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ON THE OCCURRENCE IN STELLAR SPECTRA OF THE LINES OF CLÈVEITE GAS, AND ON THE CLASSIFICATION OF STARS OF THE FIRST SPECTRAL TYPE.

By H. C. VOGEL.

EVER since the application of spectrum analysis to the heavenly bodies, the attention of astrophysicists has been attracted by a line in the neighborhood of the familiar double line of sodium, which always appears in the spectrum of the solar chromosphere in connection with the lines of hydrogen, and has an intensity of the same order as the latter. It has also been observed in the spectra of some of the few stars in which the hydrogen lines are bright. The unknown substance to which this line belongs has been called helium, and the line, on account of its proximity to the lines D_1 and D_2 of the sodium spectrum, is known as D_3.

It was reserved for Ramsay to discover, at the beginning of the present year, in the rare mineral Clèveite, a gas in the spectrum of which the helium line D_3 appeared as one of the strongest lines; and the admirable investigation of the spectrum of Clèveite gas by Runge and Paschen, shortly after this most interesting observation, is not without significance for stellar spectrum analysis, as I shall proceed to show.

I first arrange, in a convenient form for the present investigation, the table of wave-lengths which Runge[1] has given for the lines in the spectrum of gas derived from Clèveite, adding also the estimates of the intensities of the lines which Professor Runge has kindly sent me. The brightest lines are indicated by 10, while those lines are indicated by 0 which were perceptible, but too faint to permit an estimate of their intensity relatively to the stronger lines in the spectrum. The difference of intensity between the components of the close double lines is very great; it may be assumed that the more refrangible component is ten times more intense than the less refrangible.

In the course of his investigations, Professor Runge has been led to the assumption that the spectrum which he observed does not belong to a single substance, but to a heavier gas (helium) and a lighter gas. The lines of helium are indicated by an asterisk.

Only those lines between the wave-lengths 3700 and 7070 are given in the following table, as they alone need be considered in comparisons with star spectra.

SPECTRUM OF CLÈVEITE GAS.

Wave-length (Rowland)	Intensity	Wave-length (Rowland)	Intensity
* 3705.15	3	* 4026.35	5
.29		.52	
* 3733.01	1.5	* 4120.98	2.5
.15		1.14	
* 3819.75	4	4143.91	2
.89		4169.12	1
3833.7	0	4388.11	3
3838.2	0	4437.73	1.5
* 3867.61	2	* 4471.66	6
.77		.85	
3871.9	0.5	* 4713.17	3
3878.3	0	.39	
* 3888.76	10	4922.08	4
.97		5015.73	6
3926.8	0.5	5047.82	2
3936.1	0	* 5875.88	10
* 3964.84	4	6.21	
5.08		6678.4	6
4009.42	1	* 7065.51	5
4024.14	0	.77	

[1]*Sitzungsberichte* d. K. Akad d. W. Berlin, 1895. Part XXX., 639 and Part XXXIV, 759.

At a meeting of the Berlin Academy on February 8, 1894, I described the peculiar double spectrum of β Lyrae, and the corresponding published paper[1] was mainly devoted to an investigation of the changes of the bright and dark pairs of lines, which are related to the variation of the star's brightness and are probably caused by the motion of two or more bodies. It was shown that the atmospheres of the component stars must be assumed to have the same constitution, but to differ with respect to density and state of incandescence. In the same paper were also given my determinations of the wave-lengths of the different lines in the spectrum of β Lyrae, and a comparison of them with the lines in the spectrum of Clèveite gas has led to a surprising result with regard to the number of these lines which are present in the spectrum of the star.

I have lately remeasured some of the best spectrograms, and have found on them three more lines belonging to the spectrum of Clèveite gas, which were overlooked at the first measurement on account of their faintness.

Adding the line D_3 which has been known in the spectrum of this star for many years, two lines in the green, measured by Keeler[2] and by Bélopolsky[3], and finally a line whose wave-length, with that of four others, was determined by me as well as by Lockyer[4] and Bélopolsky, there results the following table of wave-lengths of the lines of Clèveite gas which are present in the spectrum of β Lyrae.[5]

[1] *Sitzungsberichte* d. K. Akad. W. Berlin, 1894, Part VI., 115.

[2] *A. and A.* **12**, 350, 1893.

[3] *Mél. Math. et Astron. St. Petersb.* **7**, 1893.

[4] *Proc. R. Soc.* **56**, 284.

[5] It should be mentioned here that, according to Keeler's observations (*Astronomy and Astro-Physics*, **12**, 361, 1893), the variable star P Cygni has a double spectrum resembling hat of β Lyrae, and that there are present in the spectrum of this star, besides the hydrogen lines $H\gamma$ and $H\beta$ and perhaps the D lines, the lines λ4922, λ5016 and D_3 of the spectrum of Clèveite gas.

An excellent photograph of the spectrum of P Cygni taken within the last few days by Dr. Wilsing confirms the observations of Keeler. The spectrum is very similar to that of β Lyrae at the time of a principal minimum; bright and dark lines are

LINES OF CLÈVEITE GAS IN THE SPECTRUM OF β LYRAE.

Wave-length	Remarks
3704	Weak absorption line. Not separable from $H\xi$.
3735	Weak absorption line. Not separable from $H\lambda$.
3820	Strong absorption line.
3869	Measured subsequently; very faint.
3874	Measured subsequently; doubtful, since the discrepancy amounts to 2 Ångström's units.
3889	Most intense line in the spectrum of β Lyrae. Without doubt a summation of the line $H\zeta$ and the strongest line in the spectrum of Clèveite gas.
3927	Weak absorption line.
3965	Observed as a sharp, strong line close to $H\epsilon$.
4010	Delicate line. Subsequent measures gave $\lambda = 4008$.
4026	Intensity nearly that of the hydrogen lines.
4120	Weak line.
4143	Delicate line.
4388	Broad absorption line.
4438	Measured subsequently; very faint; easily overlooked without a knowledge of its approximate position.
4470	Broad, conspicuous line.
4714	Observed by Lockyer and Bélopolsky.
4923, 5016	Observed by Bélopolsky and Keeler.
5876	D_3.

Incited by the interesting result of the comparison of the spectrum of Clèveite gas with the spectrum of β Lyrae, and being satisfied with the accuracy of the wave-length determinations in so short a spectrum (10^{mm} from λ 3700 to λ 4500), I searched for the lines of Clèveite gas in other stellar spectra. For this purpose I had at my disposal a wealth of observational

in close juxtaposition. The lines are, however, narrower than those of β Lyrae, and the bright lines are more intense relatively to the continuous spectrum. I have made the following determinations of wave-lengths:

λ 3836	λ 4121
3889	4143
3966	4340
3970	4371
4026	4388
4101	4470

Of the twelve lines measured, seven belong to the spectrum of Clèveite gas.

material accumulated by Dr. Wilsing, who began two years ago, in accordance with my instructions, to photograph the spectra of all stars of the first class down to the fifth magnitude, with the 13-inch photographic refractor and small spectrograph which had been used in taking the spectrograms of β Lyrae. Since the line λ4471, which plays an important rôle in the spectra of the Orion stars, belongs to the Clèveite gas spectrum, and since Ramsay's discovery has thrown light on the origin of this line, I began by examining the spectra of the brighter Orion stars.

It is not my intention to give here a detailed account of the investigation; on the contrary I shall make the account as short and condensed as possible, since a complete investigation of the spectra will be made jointly by Dr. Wilsing and myself when the material shall have been collected, and the results are expected to appear in the publications of the Observatory. At present only about a third of the spectrograms have been taken. In the following table I have therefore given only those lines which can be identified with the lines of Clèveite gas. The brightest line λ 3889.0 so nearly coincides with $H\zeta$ (λ 3889.1) that separation would not be possible, even with a considerably greater dispersion than that which was employed. However, as I have already remarked in connection with the spectrum of β Lyrae, this line may become especially conspicuous by the summation of the lines of the two different substances, and I have therefore given the estimates of brightness (omitting all other numerical results) relatively to the line of Clèveite gas which coincides with $H\zeta$. A line λ 3936.1 just perceptible in the Clèveite gas spectrum falls close to the calcium line λ 3933.8, and since the occurrence of the calcium line is of interest, as I shall show further below, I have included this line also in the table, expressly remarking, however, that its occurrence even when it is very weak, is a proof of the presence of calcium rather than that of Clèveite gas.

As I have just remarked, only the estimates of the relative intensities of the lines are given in the table (the weakest lines are represented by 1, the strongest by 10), and not the wave-

lengths deduced for each line ; but I may state that the identity of the lines with those of Clèveite gas (or calcium) was assumed when the wave-lengths agreed within two tenth-meters.

LINES OF CLÈVEITE GAS IN THE SPECTRA OF THE ORION STARS

Clèveite Gas		β	γ	δ	ϵ	ζ	λ	ν	π_3	π_5	ω
Wave-length	Intensity	Orionis	Orionis	Orionis	Orionis	Orionis	Orionis	Orionis	Orionis	Orionis	Orionis
* 3820	4	4	10	5	3	3	..	7	6	6	..
* 3868	2	1?	..	..	..	..	..	..	..	..	..
3872	0.5	..	..	..	..	..	..	..	..	..	..
* 3889	10	10	10	10	10	10	10	10	9	9	9
3927	0.5	1	..	2	..	..	..	2	3	..	..
(Ca 3934)	—	8	..	2	2	..	..	1	..	2	..
3965	4	2	..	..	..	..	3	1	2	..	..
4009	1	..	3	..	..	3	..	2	1	3	3
* 4026	5	4	8	6	4	3	6	10	8	7	7
* 4121	2.5	1	3	..	..	..	1?	..	..	..	..
4144	2	..	4	4	..	..	2	3	4	3	3
4169	1	1	..	3	..	..	..	..	..	..	..
4388	3	..	2	3	..	3	..	2	3	2	..
4438	1.5	1?	..	..	..	..	..	..	..	..	..
* 4472	6	?	4	4	2	3	..	3	3	1?	..

REMARKS.

One of the two excellent photographs of the spectrum of β Orionis was made quite narrow; between $H\gamma$ and $H\beta$ the spectrum is so dense that the delicate lines less refrangible than $H\gamma$ cannot be recognized. The other photograph, with broad spectrum, is somewhat weak near $H\gamma$, so that on this plate also the fainter lines cannot be recognized with certainty. Both plates of ϵ Orionis are too dense, so that the fine details are lost.

The five brightest Orion stars, β, γ, δ, ϵ and ζ have been investigated by Scheiner,[1] by means of the Potsdam photographs of star spectra in the $H\gamma$ region, taken with the large spectrograph, and also by Keeler,[2] who paid particular attention to the less refrangible parts of the spectrum. Scheiner found in the Orion stars the following lines of Clèveite gas:

Wave-length	Star
4388	β, γ, ϵ Orionis
4438	β Orionis
4472	β, γ, δ, ϵ and ζ Orionis

[1] *Pub. des Astrophys. Observ.*, **7**, Part II.

[2] "On the spectra of the Orion Nebula and the Orion Stars." *A. and A.*, **13**, 476, 1894.

Keeler observed in the same Orion stars and also in the trapezium star Bond 628, the lines:

Wave-length	Star
4026	β, γ, ϵ and ζ Orionis
4388	β, γ, ϵ, ζ Orionis and Bond 628
4438	β Orionis
4472	β, γ, δ, ϵ, ζ Orionis and Bond 628
4713	β, γ, δ, ϵ, ζ Orionis and Bond 628
4922 } 5016 } D_3 5876 }	β Orionis.

Hitherto the view has been held that stars of the Orion type, in which the existence of Clèveite gas may be regarded as proved by the observations given above, are rather sparsely distributed in other quarters of the heavens. Scheiner,[1] in his researches on the spectra of the brighter stars, gives the following additional stars in the spectra of which the "Orion line" λ 4472 is visible: α Virginis, β Persei, β Tauri and η Ursae Majoris. I was therefore surprised to find, on examining the spectra of about 150 of the brighter first type stars, no fewer than 25, besides the ten Orion stars and the four stars described by Scheiner, whose spectra contained the lines characteristic of the Orion stars, or in other words, the spectral lines of Clèveite gas.

A correct view of the distribution of these stars in the sky can be obtained only after the completion of the work which has been planned here—that of preparing and investigating spectrograms of all stars of the first class down to the fifth magnitude, and this work, as I have said, is only about one-third completed. I give below a few of the stars in whose spectra the lines of Clèveite gas are well marked, omitting all other lines except the calcium line λ 3934.

[1] *Pub. des Astrophys. Observ.*, 7, Part II., 152.

STARS OF THE FIRST CLASS WHOSE SPECTRA CONTAIN THE LINES OF CLÈVEITE GAS.

Clèveite Gas: Wave length	Clèveite Gas: Int.	102 Herculis	ι Herculis	α Virginis	γ Pegasi	β Piscium	β Cephei	μ Herculis	ι Andromedae	τ Herculis	ζ Draconis	η Leonis	ζ Pegasi	β Persei	η Aurigae
* 3820	4	8	5	2	9	..	5	5	..	5	3	..	..	..	7
* 3868	2	2	1	..	5	2	..	..	2	2	2	..	5	2	..
3872	0.5	1	..	..	..	..	..	..	2?	..	..	..	..	..	..
3878	0	..	1.5	2?	..	..	..	..		..	..	..	..	..	..
* 3889	10	10	9	10	10	10	10	10	10	10	10	7	10	10	10
3927	0.5	4	2	2	2	..	..	1?	2	..	..	..	..	..	..
(Ca 3934)	—	2	1.5	..	..	3	3	1?	2	1.5	..	4	..	2	..
3965	4	4	..	..	..	..	..	..	..	..	..	3	..	..	..
4009	1	3	5	3	2	2	..	4	..	..	..	..	..	..	..
* 4026	5	8	6	4.5	7	6	10	8	3	5	4	4	5	3	3
* 4121	2.5	3	2	2.5	2	..	..	4	..	..	..	..	..	..	..
4144	2	3	3	2.5	2	2	5	..	..	..	..	..	..	..	..
4169	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..
4388	3	2	4	2.5	2	..	2	..	..	..	2	..	..	..	..
4438	1.5	2	..	2?	..	2	..	..	1.5	..	..	..	1 ?	..	..
* 4472	6	3	3	3	2.5	1.5	3	3	?	2	2	2	1	1.5	4

REMARKS.

The explanation of the fact that the line λ 3965 was observed in only two stars may be, that this line is so close to the calcium line λ 3969 and the hydrogen line H_ϵ (λ 3970) that it falls within their broad, diffuse borders. This line is moreover the brightest of the lines of the "lighter gas" in the part of the spectrum which I investigated, and it is worthy of remark that in a few spectra the other lines of the lighter gas have not been observed ; hence it is possible that there are stars whose spectra contain the helium lines only. In my opinion these observations are not sufficient to prove the separate occurrence of the components of the gas obtained from Clèveite. To establish such a proof it would be necessary to investigate the less refrangible parts of the spectrum, in which the most intense lines of the lighter gas, λ 4922, λ 5016 and λ 6678 are found, and the instrumental means which are at present at my disposal are insufficient for this purpose.

The examination of these numerous spectra has again strengthened my opinion that only general and far-reaching characteristics should be considered in classifying stars according to their spectra, and that a rational system of classification is conceivable, only on the basis that the different spectra of the stars are indications of different stages of development. In my opinion it is to be regretted that, in the comprehensive spectro-

scopic Durchmusterung of stars down to the 7th magnitude, which Pickering has undertaken with an object-glass prism, the stars are classified without reference to any general considerations, but are merely divided into sixteen classes, designated by the letters *A* to *Q*, according to the appearance of the spectrum, which is frequently liable to misinterpretation in the case of improperly-timed exposures, especially those on the brighter stars.

Notwithstanding the enormous advance of stellar spectroscopy in late years, the classification of the spectra of the stars which I proposed more than twenty years ago,[1] on the basis mentioned above, has only been confirmed by more recent researches, and among others by the refined and detailed investigations of star spectra by Scheiner.

With regard to stars of the third spectral type, visual observations of the less refrangible parts of the spectrum are still to be preferred to photographs for purposes of classification. For the subdivisions *a* and *b* of my system, the criterion for deciding which of the two represents the more advanced stage of development, is entirely lacking. Only this much can be said, that in both subdivisions the atmospheres of the stars have so far cooled that dissociation has come to an end, and chemical combinations can exist. There are consequently no grounds for placing the stars of class III*b*, the absorption bands of which are mainly produced by hydrocarbons, in a special IV class. For the same reasons given above, direct observation is also very effective for recognizing the spectra of stars belonging to class II. Here also there are no grounds for introducing other subdivisions than the two which I have adopted, until more precise investigations of the spectral type II*b* shall have become available.

It is otherwise with stars of class I. In the case of these stars the application of photography allows a more complete general examination of the spectrum to be made, and a nicer discrimination of characteristic points of difference, than was possible by the older method. The study of their spectra is also

[1] *A. N.* No. 2000.

of especial interest in this respect, that starting with the simplest spectra, in which the lines of hydrogen can alone be recognized, their further development can be followed, from the first traces of lines due to other substances, to the countless lines which mark the spectra of the second type. Further researches on the details of first type spectra will perhaps make it possible to discover the beginnings and separate terms of the two divergent series which end in the apparently widely different spectra of type III*a* and type III*b*.

In particular the observations communicated above have led me to believe that the appearance of the lines of Clèveite gas in star spectra is in every way worthy of attention, and that it may furnish a useful means for the classification of spectra. With respect to its spectral behaviour, Clèveite gas has a great similarity to hydrogen, a fact which has long been recognized by the constant appearance of the D_3 line in all parts of the solar chromosphere, and also in the solar prominences, in company with the hydrogen lines, so that with these lines the appearance of the lines of Clèveite gas is first of all to be expected. The spectrum of this gas contains few lines, and can be recognized with special facility. Although the brightest line λ 3899 so nearly coincides with the hydrogen line $H\zeta$ (which is never absent in spectra of the first type) that a separation is not possible, while the summation of these strong lines will seldom appear as plainly as in the case of β Lyrae, nevertheless the lines λ 3820, λ 3868, λ 4026 and λ 4472, and in the less refrangible regions the lines λ 4922, λ 5016 and the D_3 line (λ 5876) can be found so easily, and identified with such certainty, that the proof of the existence of Clèveite gas offers no difficulty. In the more refrangible part of the spectrum, it is sufficient to ascertain the presence of the line λ 4026, which does not fail in any of the spectra, hitherto investigated, containing the lines of Clèveite gas. In the prismatic spectrum it lies nearly half way between the hydrogen lines $H\epsilon$ and $H\delta$.

A second appropriate means of distinguishing subdivisions of the first spectral class is furnished by the appearance of the

calcium lines $\lambda 3933.8$ and $\lambda 3968.6$, the latter of which nearly coincides with the hydrogen line $H\epsilon$ ($\lambda 3970.2$). If the former line is narrow and sharp, the influence of the latter on the $H\epsilon$ line will be very small. If, however, the calcium lines become broader and more intense, the widening of $H\epsilon$ becomes very perceptible, and both lines soon exceed, with respect to breadth and intensity, the strong and generally broad hydrogen lines in spectra of the first type. At a still more advanced stage of development they form the pair of lines, so characteristic of the second spectral type, which Fraunhofer designated by the letter H.

I believe that the divisions of the stars of the *first* spectral class, which I venture to give below, corresponds to the present state of science, and that it will be serviceable for a considerable time in the future. In its arrangement I have endeavored to keep as close as possible to my previous method of classification. According to the present standpoint, it might seem better to give the first place to the few stars whose spectra contain *bright* lines, as representing the first stage of development; but since, in my opinion, a final decision of this question is not yet possible, I have retained the order of my former series, on formal grounds, and have again placed these stars together under a third subdivision, *c*.

In view of more recently acquired knowledge, the definition of class I*b* was found to be inadequate, and in the course of time I recognized the necessity of a change, and indeed suggested one.[1] It has lately been proposed, on the ground of elaborate researches on the spectra of β Orionis and α Cygni, to define class I*b* of my earlier classification as that class of stars in whose spectra the hydrogen lines and metallic lines all appear to be of equal breadth and sharp definition.[2] However justifiable it may be to regard the peculiarly sharp spectral lines of the stars above mentioned, and a few others of the same kind, as worthy of special consideration, the adoption of this proposal would make it necessary to separate a number of stars (including those of

[1] *A. N.* No. 2839.

[2] Scheiner, *Spectralanalyse der Gestirne*, p. 271.

Orion) whose relationship is placed beyond question by the investigations I have referred to, and to place them with α Cygni, which has a materially different spectrum. The hydrogen lines in the spectra of class I differ so greatly in breadth and diffuseness, that the narrow and sharply bounded lines in the spectra of β Orionis and α Cygni may be regarded as a remarkable, but at the same time as only an individual peculiarity of these spectra. In my opinion, now that Clèveite gas has been discovered, the definition of spectra of class I*b* can be finally established.

Class I of Stellar Spectra.

Continuous spectra, whose more refrangible parts, blue and violet, are remarkable for their intensity. The spectra are crossed by the entire series of hydrogen lines, which appear as dark, broad and diffuse, rarely as sharply defined (and then narrow) lines of absorption. In general, the intensity of the hydrogen lines materially exceeds that of other metallic lines in the spectrum.

Quite rarely the lines of hydrogen and other substances do not appear as absorption lines; in this case they appear as bright lines on a continuous spectrum.

a.

1. Spectra in which the hydrogen lines are broad and strongly developed, but in which other spectral lines cannot be recognized.

2. Spectra in which lines of other metals (calcium, magnesium, sodium) appear, in addition to the hydrogen lines, but which contain no lines of Clèveite gas. The calcium line λ 3934 in these spectra appears sharply defined; its breadth is not nearly equal to that of the hydrogen lines. The spectral lines of other metals are delicate, and not easily recognized with low dispersion.

3. Spectra in which the calcium line λ 3934 has nearly the same intensity as the hydrogen lines. In occasional instances it is still sharply defined at the edges; or it may be broader and more intense than the hydrogen lines, and very diffuse, forming,

with the hydrogen line $H\epsilon$ (λ 3970), which is greatly intensified and broadened by the calcium line λ 3969, a conspicuous pair, In the spectra of this division the lines of Clèveite gas cannot be recognized; on the other hand, numerous strong lines of different metals, particularly the lines of iron, are always present. The lines of hydrogen are still always dominant. $H\delta$ is plainly apparent among the other lines, and the group G is less conspicuous than $H\gamma$.

This subdivision forms the direct connecting link with the spectral class II, in which the hydrogen lines no longer play a prominent part in comparison with the lines of other metals.

b.

Spectra in which, besides the still dominant hydrogen lines, the lines of Clèveite gas appear, and above all the lines λ 4026, λ 4472, λ 5016 and λ 5876 (D_3). (The strongest line in the violet λ 4889, is so nearly coincident with $H\zeta$ that it is not a reliable criterion of the presence of lines of Clèveite gas in star spectra). The lines of calcium, magnesium, sodium and iron are also more or less numerous in spectra of this subdivision.

c.

1. Spectra with bright hydrogen lines.
2. Spectra in which, besides the hydrogen lines, the lines of Clèveite gas and the lines of calcium, magnesium and other metals are bright.

It scarcely needs to be mentioned that a sharp separation of the different subdivisions is not possible, and that, to a certain extent, the assignment of spectra to them will depend upon the excellence of the instrument which is used, and the correctness of the exposure when plates are obtained by photography. According to our experience up to the present time, the discrimination between I*a*1 and I*a*2 offers greater difficulty than that between other subdivisions, and the number of spectra coming under the heads I*a*1 and I*c*1 will always be small.

Under I*a*2 may be placed the spectra of α Canis Majoris and

α Lyrae; under Ia3 α Cygni, standing near the limits of transition into class II, β Cassiopeiae and α Canis Minoris. To subdivision *b* belong most of the Orion stars, β Persei (Algol), α Virginis, and one of the components of β Lyrae, while the other component of β Lyrae is to be classed under Ic2. If the peculiar spectrum of Pleione is regarded as a double spectrum, it belongs equally to Ia1 and Ic1, as the hydrogen lines (no other lines can be recognized with the Potsdam spectrograph) appear as broad absorption lines with bright lines in the middle. If however it is assumed that the hydrogen lines have merely suffered a double reversal, the spectrum of this star is to be classed under Ia1.

Judging by the number and strength of the metallic lines which appear coincidently with the lines of hydrogen, the spectra of class Ib are, with respect to their places in the scale of development, to be classed with Ia2 and Ia3. Although at present no such clearly marked evidence of transition into class II can be given for these stars as for stars of the subdivision Ia3, some of the spectra, in which the existence of Clèveite gas can be proved, contain a large number of lines, so that the descent between class Ib and class II is at least not too abrupt. That there is actually a gradual transition cannot be doubted, for Clèveite gas is found in the Sun, a star of the second spectral class, although it is known that the lines of this gas are not there reversed.

ON A PHOTOGRAPHIC SEARCH FOR A SATELLITE TO THE MOON.

By E. E. Barnard.

During the total lunar eclipses of March 10 and September 3, 1895, I took the opportunity at the Lick Observatory to make a series of photographs of the Moon in the shadow, with the six-inch Willard lens.

These pictures were made to test the possible existence of a lunar satellite. Though, of course, no satellite was found, the results are nevertheless very interesting.

If our Moon had a small satellite revolving about it, such, on account of the enormous brightness of the Moon itself, might never be seen by any of the visual methods. To successfully photograph it under the ordinary conditions would be perhaps impossible because of the spreading of the Moon's light.

If, however, we could obscure the Moon so that it could not illuminate our atmosphere in its direction, we might give a sufficiently long exposure to show any such satellite if it existed near the Moon, and of a brightness so great as the 10th or 12th magnitude.

Such an opportunity is presented during a total lunar eclipse, at which time the faintness of the Moon and its red color would prevent its light spreading on the plate or illuminating our atmosphere. If during any part of this time the satellite should be outside of the shadow and fully illuminated it might be easily photographed.

There does not seem to be any reason to suppose that any such satellite attends our Moon; yet it is a point that has sufficient plausibility about it to suggest a photographic search.

It was therefore with this end in view mainly that I decided to make a series of photographs with the Willard lens during

the total phases of the lunar eclipses of 1895, March 10 and September 3.

The results obtained during the eclipse of March 10, 1895, were not entirely satisfactory because the sky was rather hazy. The photographs then obtained, however, showed the Moon clearly in the shadow.

The eclipse of 1895, September 3, was entirely satisfactory, as the sky was perfectly clear and the duration of totality was very long.

On this last occasion a series of six splendid photographs were obtained of the total phase.

The motion of the Moon of course made it necessary to guide the telescope carefully by hand independently of the regular clock motion. It was difficult to find any lunar marking sufficiently small and distinct for accurate guiding.

The Mare Crisium was finally selected as the most suitable mark, and this was kept carefully and accurately bisected by the wires in the guiding telescope; it required constant attention as the motion of the Moon was considerable. That this was carefully attended to is shown by the sharpness of the resulting images. I have certainly never seen such exquisite pictures of the Moon as those made during totality with the Willard lens. The details of the surface are clearly and beautifully shown and the Moon stands out from the sky like a beautiful globe.

None of these pictures made during the two eclipses shows anything which might be taken for a lunar satellite.

During the eclipses of the Moon in January (28) and July (22), 1888, photographs of the total phases were made at the Harvard College Observatory, and I believe with the same idea of a search for a possible satellite.

Inasmuch as none of these photographs made during these different eclipses has shown any evidence of a lunar satellite, I think we are fairly justified in assuming that such a body does not exist of sufficient brightness to be detected with our most sensitive photographic plates, and a further search for it therefore appears quite unnecessary.

In speaking of the Harvard College photographs of the total lunar eclipses of 1888, I have before me now a glass copy of one of these made during totality January 28, 1888. This picture, though it shows the Moon well in the shadow, does not show the details distinctly; they are more or less blurred and lost through a lack of careful guiding. From the star trails it would appear that the telescope had been adjusted to the motion of the Moon and then left to take care of itself during the exposure.

Of the six photographs made at the Lick Observatory during totality on September 3, 1895, I have selected the one nearest the time of central eclipse for reproduction here (Plate X). This was exposed from $9^h\ 57^m$ to $10^h\ 06^m$ Standard Pacific Time, and was made on a Seed 10 x 8 plate of sensitometer No. 27. The central phase of the eclipse occurred at $9^h\ 57^m$ according to both my observations and the Nautical Almanac. The Moon's center was then about 15′ south of the center of the shadow. The photograph therefore represents the Moon while it was most deeply immersed in the shadow.

Following are the times of exposure of all the negatives made during totality September 3, 1895:

$9^h\ 11^m$ to $9^h\ 17^m$	Standard	Pacific Time.
$9^h\ 24^m$ to $9^h\ 47^m$	"	"
$9^h\ 57^m$ to $10^h\ 06^m$	"	"
$10^h\ 14^m$ to $10^h\ 25^m$	"	"
$10^h\ 30^m$ to $10^h\ 35^m$	"	"
$10^h\ 39^m$ to $10^h\ 51^m$	"	"

KENWOOD OBSERVATORY, CHICAGO,
Nov. 21, 1895.

PHOTOGRAPH OF THE NEBULA *N. G. C.* 1499 NEAR THE STAR ξ PERSEI.

By E. E. Barnard.

In *A. N.* 3082, Dr. Archenhold gives an account of a large nebula which he had photographed near the star ξ Persei. He also gives an outline map of the nebula, showing its position with reference to the stars in and near it.

From his chart, the nebula is shown to extend from R. A. $3^h\ 47^m$ to R. A. $3^h\ 56\frac{1}{2}^m$, and from Dec. $+ 35°.4$ to $+ 36°.6$.

This nebula was discovered by me some six years previous to Dr. Archenhold's photograph, *viz.*, 1885, November 3, with the 6-inch Cooke Equatorial of Vanderbilt University Observatory, at Nashville, Tenn. It is No. 1499 of Dreyer's *N. G. C.*, where it is described as "very faint, very large, diffused." It was a very difficult object with the 6-inch.

I have made several photographs of this nebula with the Willard lens of the Lick Observatory. The last one of these was made 1895, September 21, and was given 6 hours' exposure. An enlargement from this is here reproduced (Plate XI). The scale of this picture is $0°.9 = 1$ inch.

It will be seen from the photograph that this is a very remarkable nebula. There are a number of angular condensations in it—especially in the north preceding and north following edges. Indeed the outlines everywhere seem to be brighter and unequally condensed. In its northern part is a very small, very dark spot, about $6'$ in diameter—doubtless a hole in the nebula.

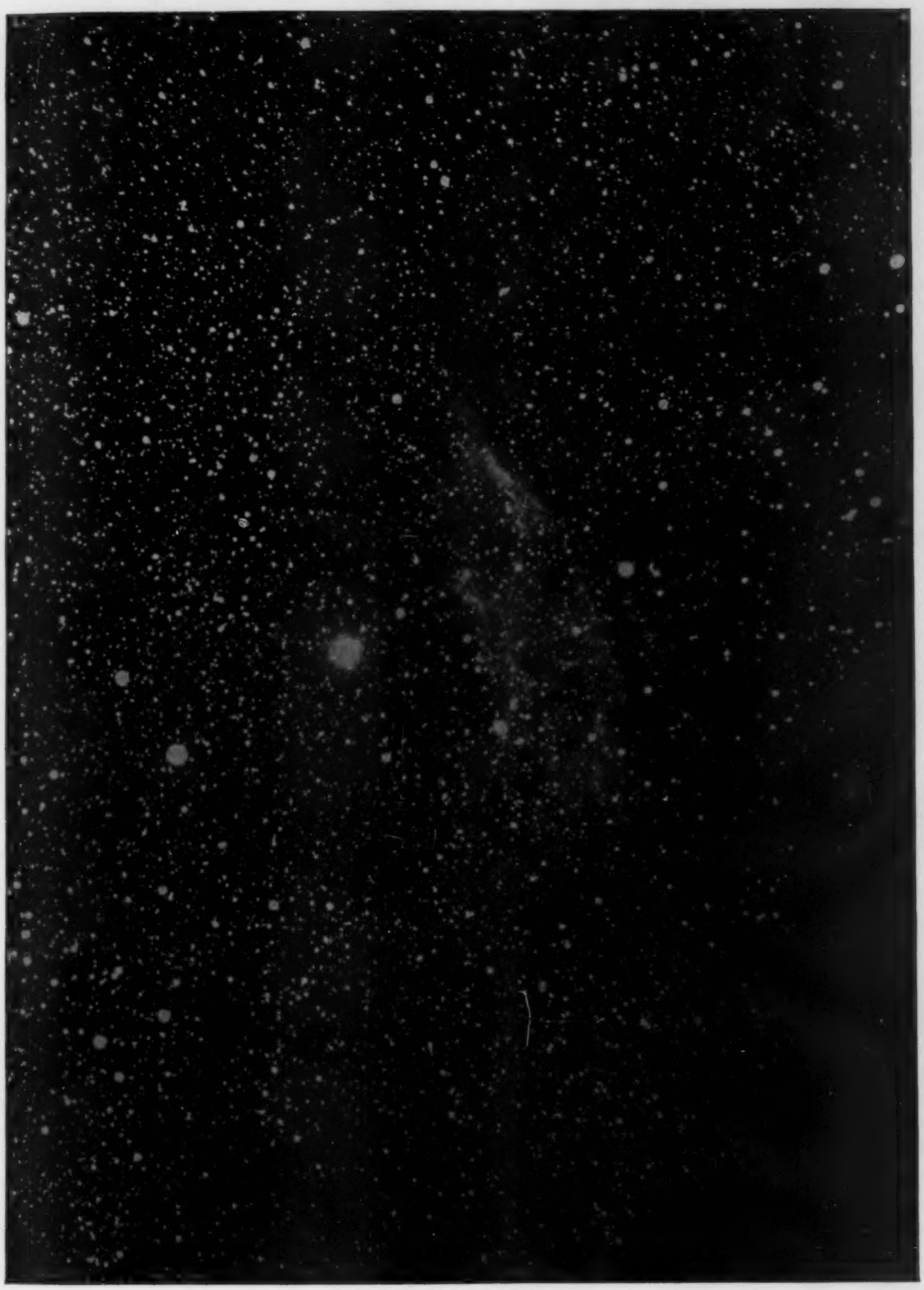
It will be noticed that this object lies on the edge of a region comparatively devoid of small stars. This is a very suggestive fact noticeable in the case of most of these large diffused nebulæ, as shown in photographs of the large nebulous regions of Cygnus, Monoceros, Cepheus, Scorpio and the present one of Perseus, where the nebulosity either lies in or on the edges of a vacancy among the stars.

Kenwood Observatory, Chicago,
November 20, 1895.

PLATE XI

E

S



N

W

PHOTOGRAPH OF THE NEBULA *N. G. C.* 1499

By E. E. Barnard, Lick Observatory

Exposure 6h | Sept. 21, 1895 | Six-inch Portrait Lens

CELESTIAL PHOTOGRAPHS WITH A "MAGIC LANTERN" LENS.

By E. E. BARNARD.

I HAVE elsewhere (*A. and A.*, December, 1895, *M. N.*, June, 1895), given some account of the performance of a small lens in photographing large areas of the sky, and for the delineation of very large diffused nebulosities, etc. This lens is a very small one belonging to an ordinary "magic lantern;" it is one and one-half inches in diameter and some four or five inches equivalent focus.

Six photographs of various parts of the Milky Way made with this lens are here presented (Plate XII). These will at once show the value of such an instrument for this class of work.

I have made a great number of plates similar to these, of the brighter cloud-regions of the Milky Way, and propose soon to construct a photographic chart from them. The present photographs show six of the most remarkable parts of the Milky Way as seen from this latitude. They run from the Eagle to near the southern horizon in Sagittarius and the Scorpion.

For convenience in arranging these pictures, they do not follow each other in the order of position in the sky.

Fig. 1 (R. A. $18^h\ 40^m$, Dec.—8°, August 16, 1895, exposure $5^h\ 10^m$) shows the great star-cloud near Messier 11 which was first photographed by the writer with the 6-inch Willard lens of the Lick Observatory in the summer of 1889 (see this JOURNAL January, 1895, for a reproduction of one of the photographs of this object with the Willard lens; also the *Photographic Times* for August, 1895, where a splendid reproduction is given).

The present picture with the lantern lens shows this magnificent star-cloud on a scale scarcely different from the naked eye view of it. It is seen to rather abruptly project over a vacant

part of the Milky Way to the west. The connection of this region with that in Fig. 4 is easily made out.

Fig. 2 (R. A. 17^h 56^m, Dec. — 28°, August 23, 1895, exposure 1^h 10^m), shows the great star-clouds of Sagittarius—just east and north of the tail of the Scorpion. The bright spot in the upper part of this plate is the nebula Messier 8. This portion of the Milky Way was the first that I succeeded in photographing in 1889. (For a reproduction of this region with the Willard lens see Proctor's *Old and New Astronomy*.) The picture with the larger lens shows a great amount of very curious structural detail.

Fig. 3 (R. A. 19^h 20^m, Dec. + 8°, August 17, 1895, exposure 2^h 45^m). This is the region near Altair (the bright star to the left of the center of the picture). It joins that of Fig. 1 to the northeast. The smallest of the cloud-forms in this plate somewhat resembles the great cloud near Messier 11.

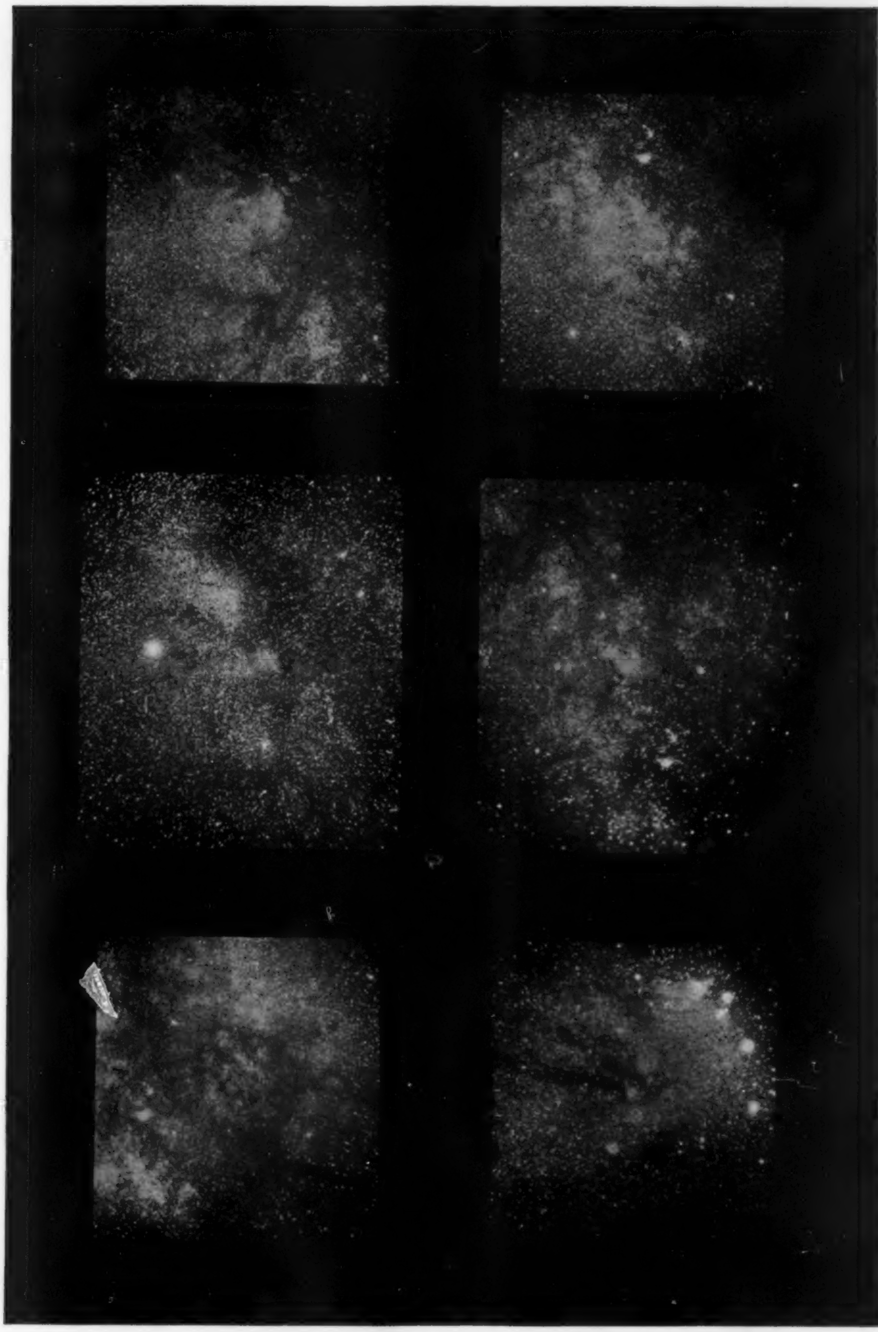
Fig. 4 (R.A. 18^h 0^m, Dec. — 19°, June 19, 1895, exposure 2^h 55^m). This picture shows the remarkable star-cloud in Sagittarius lying between the Trifid nebula and the Swan or Omega nebula. The two small, sharply defined holes near the middle of this cloud are the most striking features about it, except the dark lanes and star streams in its southern part, which are not well shown here on account of the smallness of the scale. For pictures of this region with the Willard lens see Miss Clerke's admirable *History of Astronomy during the Nineteenth Century*, and the *Photographic Times* for August, 1895.

Fig. 5 (R. A. 17^h 40^m, Dec. — 23°, June 26, 1895, exposure 4^h 05^m). This shows the singular region between the Trifid nebula and the star Theta Ophiuchi. The center of the picture is occupied by small cloud-forms, which, in a picture made with the Willard lens, appear to be nebulous. A vacant region is seen passing around to the left and below the star Theta Ophiuchi in the lower right-hand corner of the picture — this has its origin in Fig. 6. This remarkable structure of the Milky Way about Theta Ophiuchi is shown in a photograph with the Willard lens in *Knowledge*, November, 1894, and in the *Photographic Times* for August, 1895.

PLATE XII

N

1 2



E 3 4 W

5 6

S

PHOTOGRAPHS OF THE MILKY WAY

Made with a 1½-inch Magic Lantern Lens

By E. E. BARNARD, Lick Observatory

1895

Fig. 6 (R. A. 16^h 20^m, Dec. $-23°$, March 30, 1895, exposure 2^h 18^m), shows the new nebulous region about Antares. This remarkable region was first shown on a photograph with the Willard lens March 23, 1895, at which time its nebulous character was first made manifest (see *A. N.* No. 3301; *M. N.* June, 1895).

The present picture shows two remarkable vacant streams running eastward from the great nebula about Rho Ophiuchi. The upper one of these vacant lanes is the one shown in Fig. 5, which passes easterly and southwesterly of Theta Ophiuchi. A large, long nebula will be seen about the star Nu Scorpii in the upper right-hand part of this picture; this object is very remarkable, as shown on a plate with the Willard lens. It was discovered with the lantern lens.

The scale of all these pictures is about 10° to one inch. The exposures in making them, it will be seen, are rather long; such long exposures are unnecessary. The small camera was fastened to the Willard box and usually given the same exposure as with the large lens. For instance, the great star cloud near Messier 11 is well shown in from ten to fifteen minutes.

In conclusion, I think these six photographs with the small lens show us in a most striking manner how the most valuable and important information may be obtained with the simplest means.

Kenwood Observatory, Chicago,
November 18, 1895.

STARS HAVING PECULIAR SPECTRA.

EIGHT NEW VARIABLE STARS IN CETUS, VELA, CENTAURUS, LUPUS, SCORPIO, AQUILA AND PEGASUS.[1]

By M. FLEMING.

An examination of the Draper Memorial photographs received during the past summer from the Arequipa Station has added several stars to the lists of those already known to have peculiar spectra. The objects are contained in the following table, which gives the designation of the star, the approximate right ascension and declination for 1900, the catalogue magnitude and a brief description of the photographic spectrum.

Designation	R. A. 1900	Dec. 1900	Magnitude	Description
B. D.—1° 2312	9^h $45^m.9$	− 1° 33′	8.9	Type IV
Z. C. 13^h 717	13 13 .4	−73 55	8½	Type IV
A. G. C. 19416	14 15 .7	−49 24	8½	Type IV
Z. C. 17^h 921	17 15 .3	−41 39	8½	Peculiar
....	18 7 .8	−19 5	...	Type V
C. D. M.—30° 15469	18 9 .7	−30 54	10	Type V

—Lupi. *A.G.C.* 19416. In using the photographic chart plates to identify this fourth type star, Miss L. D. Wells discovered distinct evidence of its variability. A further examination of photographic charts taken on May 24, June 13, June 13, July 2, July 4, July 9, July 9, 1889; April 20, May 22, May 28, 1890; May 21, May 21, May 27, May 27, 1891; May 14, May 16, May 18, August 10, August 13, 1892; April 28, April 28, May 1, May 10, May 15, June 3, June 23, June 23, June 26, 1893; April 14, April 14, May 21, May 22, July 26, 1894; March 12, March 12, April 8, April 15, and April 16, 1895, gave the magnitudes 11.2, 10.9, 11.2, 11.2, <9.9, 11.2, 11.2; <8.7, 10.9, 11.1; 10.9, 10.9,

[1] Communicated by Edward C. Pickering, Director of the Harvard College Observatory.

11.0, 11.2; 11.2, 10.6, <10.4, <10.0, <9.9; 10.8, 11.0, 10.6, <9.6, <10.0, 11.1, 10.8, 11.0, 11.2; 10.8, 10.6, 10.6, 10.8, 9.6?; 10.3, 10.4, 10.4, 9.2, and 9.8 respectively, thus confirming the variability of this star.

C. D. M. $-30°$ 15469. The presence of the bright lines $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, and $H\zeta$ in the photographic spectrum of this star was discovered by Professor James E. Keeler, at this Observatory, on October 18, 1895. This star is of interest since its photographic spectrum closely resembles that of η Carinae.

In addition to the objects described above, six stars having spectra of the third type, and also bright hydrogen lines, have been proved to be variable. The following table contains the constellation, designation, approximate right ascension and declination for 1900, the number of plates examined and the maximum and minimum magnitude as derived from the photographs.

Constellation	Designation	R. A. 1900	Dec. 1900	No. Plates	Magnitude Max.	Magnitude Min.
Vela	*C.D.M.*$-41°$ 6787	$11^h\ 44^m.1$	$-41°\ 12'$	27	7.8 —	12.4
Centaurus	*Z. C.* 11^h 3351	11 50 .0	-58 42	55	8.6 —	13.0
Centaurus	*A. G. C.* 19643	14 25 .1	-29 39	26	7.7 —	8.8
Scorpio	....	17 8 .3	-33 19	68	9.4 —	14.1
Aquila	....	19 53 .7	-8 10	52	10.0 —	<12.4
Pegasus	*B. D.* $+5°$ 4928	21 56 .1	$+5$ 39	41	8.2 —	<13.0

—Velorum. *C.D.M.* $-41°$ 6787 The magnitudes of this star, as derived from photographs taken on May 25, June 1, June 13, 1889; April 1, May 11, May 14, May 25, May 28, 1890; June 23, July 2, July 3, 1892; April 28, May 1, May 1, May 5, May 8, June 27, June 27, 1893; April 9, May 19, June 18, June 18, 1894; Feb. 20, April 26, May 1, May 21 and June 4, 1895, are 8.1, 7.8, 8.4; 8.2, <8.9, 8.4, 9.2, 9.1; <9.6, <9.6, <9.6; 12.4, <11.9, 12.4, <10.2, <9.8, 11.2, 11.2; 11.6, 11.2, 9.7, 9.6; <10.4, <9.4, 9.3, 9.2, and 8.2 respectively.

—Centauri. *Z. C.* 11^h 3351. The magnitudes of this star, as derived from photographs taken on May 20, May 27, May 31, June 13, June 13, 1889; April 3, April 13, May 5, May 9, May 26, 1890; May 3, 1891; March 18, August 5, August 7, August

12, 1892; January 13, January 13, January 13, February 25, April 6, April 28, May 2, May 2, May 2, May 2, May 4, May 4, May 4, May 4, May 12, May 16, May 20, June 22, June 26, June 26, 1893; April 17, May 15, May 15, May 17, May 23, June 1, June 1, June 1, June 1, 1894; March 26, April 3, April 3, April 10, April 11, April 14, April 21, May 9, June 4, June 14, and June 15, 1895, are 9.2, 9.5, 10.0, 10.9, 10.8; <11.3, <9.0, 11.5, 11.4, 10.2; <9.1; 10.2, <8.6, <9.8, <9.8; <9.7, <11.6, <11.4, <9.0, 8.6, 10.7, 10.8, 10.9, 10.9, 11.0, 10.8, <10.9, 11.0, 11.0, <9.7, <10.6, 11.3, <11.9, 12.4, 12.6; 10.8, 9.4, 9.5, 9.5, <9.1, 9.8, 9.8, 9.8, 9.8; <10.8, <11.7, <12.2, 13.0, 12.9, <10.4, <10.4, 11.4, 9.6, 9.2, and 8.8 respectively.

—Centauri. *A. G. C.* 19643. The magnitudes of this star, as derived from photographs taken on June 3, June 13, June 13, June 21, June 25, July 1, August 1, 1889; April 14, May 13, May 15, May 29, June 7, June 23, 1890; May 27, June 27, 1891; April 23, April 23, 1892; May 31, June 3, June 3, June 5, 1893; June 19, July 5, July 6, 1894; March 12 and April 19, 1895, are 8.8, 8.3, 8.4, 8.7, <7.8, 7.7, 8.1; 8.4, <8.6, <8.7, 8.2, 8.2, 8.2; 8.8, 8.0; 7.8, 7.8; 8.0, 8.2, 8.1, 8.2; 7.9, 8.1, 8.0; 8.8 and 8.8 respectively.

—Scorpii. R. A. $17^h 8^m.3$; Dec. $-33° 19'$. The magnitudes of this star, as derived from photographs taken on June 4, June 27, July 3, July 5, July 13, July 13, 1889; March 25, May 9, May 9, May 10, June 7, June 14, June 21, June 23, September 5, September 6, 1890; May 18, May 18, May 20, May 29, August 3, August 19, 1891; May 17, May 17, June 13, August 10, August 22, October 6, 1892; April 27, April 28, May 7, June 8, June 16, June 16, June 23, July 6, July 6, August 1, 1893; April 26, May 2, May 2, May 14, May 23, May 24, June 14, August 14, August 31, 1894; April 6, April 6, April 29, May 11, May 11, May 11, May 23, June 1, June 1, June 1, June 3, June 14, July 1, July 1, July 1, July 1, July 8, July 8, July 18, August 3, and August 3, 1895, are <9.2, <9.3, 13.4, 13.5, <13.4, <12.9; 11.0, <10.3, <9.8, <9.4, 12.2, 12.2, 12.8, 12.5, 14.1, <13.1; 11.6, 11.6, 11.5, <10.5, <9.2, <9.3; 10.6, 10.6, 11.4, <10.3, <9.7, <12.4; 11.4, 11.3,

11.2, <10.5, <9.4, <10.3, 11.6, <9.2, <10.5, <12.1; 12.1, <11.8, <9.3, 11.5, 11.4, <10.3, 11.4, 12.4, <10.4; <13.4, <13.3, <9.6, 10.3, 10.3, 10.4, 9.8, 9.4, 9.5, 9.6, 9.4, 9.7, 9.9, 9.8, 9.9, 9.8, 10.3, 10.1, 10.4, 10.6, and 10.7 respectively.

—Aquilae. R. A. $19^h\ 53^m.7$; Dec. $-8°\ 10'$. The magnitudes of this star, as derived from photographs taken on November 3, November 7, 1888; August 3, August 4, August 30, September 19, 1890; May 17, May 19, June 2, June 2, June 5, August 1, August 19, September 10, 1891; April 3, May 17, May 17, June 29, July 27, August 19, August 23, September 6, September 12, September 16, September 18, September 26, September 27, 1892; July 21, July 22, July 22, August 3, August 4, August 10, August 15, August 17, September 2, September 13, September 20, October 20, October 20, 1893; June 8, June 13, June 14, August 18, August 28, October 15, November 1, 1894; May 24, June 1, June 3, June 4, and June 11, 1895, are 10.6, 10.8; <11.2, <10.5, <11.1, <8.9; <11.6, <10.9, <10.5, <11.1; <9.2, <10.7, <10.6, <11.1; <10.5, <12.4, <11.6, <8.7, <11.7, <9.2, <9.1, <11.6, <11.0, <11.1, <9.2, <11.2, <12.1; <12.3, <12.3, <11.0, <11.2, <11.5, <11.3, <9.8, <9.2, 11.9, <11.5, 11.8, <12.2, <11.1; <9.6, <11.3, <10.1, <11.0, <10.3, <10.7, <9.1; 10.1, 10.0, 10.0, 10.0, and 10.2, respectively.

— Pegasi. *B. D.* $+5°$ 4928. The magnitudes of this star, as derived from photographs taken on November 18, 1889; June 30, August 25, 1890; June 13, June 13, June 19, August 1, August 24, September 4, September 20, October 1, October 3, October 8, October 14, October 16, October 20, October 21, 1891; September 7, September 8, September 10, September 11, September 18, September 27, September 29, September 30, October 8, October 10, October 13, October 22, 1892; July 24, August 17, September 20, September 29, September 29, October 25, November 2, 1893; May 21, October 5, November 13, November 16, 1894; and June 1, 1895, are <12.8; 9.0, 12.2; 12.0, 12.2, 12.4, <11.4, <10.5, <12.0, <11.6, <11.0, <9.2, <10.9, <13.0, <12.6, 12.8, <11.0; <12.8, <12.9, <13.0, <12.4, <13.0, <12.7, <12.5, 12.8, <11.8, <12.1, 11.8?, 11.8;

<12.1, <10.1, <10.2, <9.7, <9.6, 10.0, 10.0; <13.0, <8.5, 12.8, <12.5; and 8.2, respectively.

In the Wolsingham Observatory Circular, No. 42, issued July 15, 1895, the Rev. T. E. Espin announces the probable variability of a star in R. A. $19^h\ 52^m.4$; Dec. $-2°\ 11'$ (1900). On September 13, 1895, a star nearly in this position was discovered independently here, by means of its photographic spectrum, and its variability confirmed from photographic plates. The magnitudes of this star, as derived from photographs taken on August 23, October 18, 1888; August 4, August 5, August 30, September 30, 1890; May 19, May 19, June 2, June 2, September 2, September 17, 1891; April 3, May 17, May 17, June 29, August 23, September 1, September 5, September 18, September 27, 1892; July 20, July 20, July 20, July 21, July 21, August 10, August 10, August 15, August 15, September 2, October 2, October 9, October 20, October 20, 1893; June 29, July 21, August 10, 1894; May 24, and July 2, 1895, are <12.2, 9.8; <11.6, <11.7, <12.2, 12.1?; <9.4, <12.0, <11.5, <11.2, <10.9, <11.9; 9.2, 9.9, 10.1, <8.7, <8.9, <12.3, <11.2, <9.2, <12.2; <11.7, <10.4, <11.2, 11.8, 11.8, <10.9, <10.1, <9.7, <10.2, <10.9, <9.8, <11.3, <11.9, <12.2; 10.9, 11.2, 11.6; 8.4, and 8.6, respectively.

— Cetus. *B. D.* $-1°$ 475. The variability of this star, whose approximate position for 1900 is in R. A. $3^h\ 14^m.3$; Dec. $-1°\ 26'$, was discovered by Miss L. D. Wells, from a comparison of photographic charts. The magnitudes, as derived from photographs taken on September 6, October 17, 1888; December 19, December 23, 1889; January 4, January 9, January 14, December 28, 1890; March 11, September 17, September 17, September 20, November 25, December 1, December 8, December 10, December 18, 1891; January 5, October 5, December 16, December 23, December 24, December 28, 1892; September 17, September 20, September 20, October 4, October 5, October 6, November 10, November 26, 1893; January 23, July 16, August 16, November 16, November 16, 1894; January 19, August 6, and October 10, 1895, are <10.4, 11.6; 9.8, 9.6; 10.0, 9.7, 9.9, 10.1; <10.5, 10.8,

10.6, 11.0, <10.6, <10.6, 10.4, 10.2, 10.0; 9.7, 11.4, 11.7 ?, 10.3, 11.7 ?, 10.2; 10.2, 10.0, 10.4, <10.3, <10.4, <10.0, <9.9, <12.5; 9.7, 9.9, 9.3, 12.2, 12.3; 9.6, 9.4, and 12.4, respectively.

In the ASTROPHYSICAL JOURNAL, **2**, 198, the star *S. D.* $-7°$ 2873, in the table, is given in the constellation Hydra (following Heis). The constellation should be Sextans, as given in the notes, p. 200.

November 19, 1895.

315

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. X.

By Henry A. Rowland.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5669.258		1	5680.470		00
5669.464		0000 N d?	5680.769	A?	0000
5669.962		0	5680.978	A	000
5670.163	Ni	0	5681.292		000
5670.364		0000	5681.462		000
5670.569	A	000	5681.747		0000
5671.071	V	0	5681.965	A	00
5671.285		0000 N	5682.031	A?	0000
5671.712		00 N	5682.427	Ni	2
5672.047	Sc	0	5682.718		000
5672.485		0000 N	5682.869 s	Na	5
5673.022		0000	5683.230		000 N
5673.272		0000	5683.696	-, A?	000
5673.634		000 N	5683.989	A	000
5674.198	A	0000	5684.098	A	0
5674.387		0000	5684.118		0000
5674.496	A	0000	5684.415		1
5674.835		0000 N	5684.710	Si	3
5675.305		0000 N	5684.950		0000 N
5675.647 s	Ti	2 N	5685.250	A?	0000
5675.946		000 N d?	5685.657	-, A	00 d
5676.568		0000	5685.996	A?	000
5677.007	A	000	5686.100		000
5677.175		0000	5686.371		0000
5677.680		0000	5686.429		0
5677.919		00	5686.580		000
5678.277		0000	5686.757	Fe	3
5678.621		000	5687.063		000
5678.830		000	5687.192		0000
5679.025	-, A?	0000 N	5687.697	-, A	0
5679.249 s	Fe	3	5687.834	A?	000
5679.501		0000 N	5688.436 s	Na	6
5679.821	A	0000 N	5688.759		0000
5680.149		000	5688.810	A	00

What is known as the "low sun band" begins at λ 5670 and extends nearly to the "rain-band" at λ 5860. Its existence is supposed to be due mostly to some dry gas in the Earth's atmosphere. There are, however, probably water-vapor lines scattered through this region; and some of the lines are known to be due to oxygen.

The "rain-band" begins at λ 5860 and extends to λ 6030.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5689.255	A?	0000	5702.876	Ti	000
5689.694	Ti	0	5703.012	A	0000
5689.812	A?	0	5703.136		000
5690.117	A	000	5703.308		0000
5690.286		0000	5703.438	A	000
5690.447	-, A	000	5703.591		0000
5690.646	Si	3	5703.797	V	1
5691.715	Fe	2	5703.915		000
5691.919		00	5704.427	A?	000
5692.641	A	1	5704.608		0000
5692.970	A?	{ 000	5704.729	A?	0000
5693.095		{ 000	5704.960	A	0
5693.330		0000	5705.282	A?	0000 N
5693.547		000 N	5705.525	A?	0000
5693.865	Fe	3	5705.688	Fe	1
5694.379	A?	000	5706.215	Fe	3
5694.962	Cr	0	5706.329		0
5695.207	Ni	2	5706.941		00 N
5695.456	A?	0000	5707.204	V	0
5696.160	A	00	5707.265	Fe	1
5696.320	La	0	5707.462		000
5696.582	A?	000	5707.614		0000
5696.869		0000 N	5707.927		000 N
5697.040	A	00	5708.135		0000 N
5697.614	A?	0000	5708.317	Fe	1
5697.794	A	000	5708.622 s	Si	3 N
5698.047	A?	0000 Nd?	5708.881		0000
5698.242	Fe	0	5709.130		000 N
5698.400	A	0	5709.328		0000
5698.555	Fe, Cr	1	5709.601 s	Fe	5
5698.746	V	1	5709.775 s	Ni	5
5698.910	A	000	5710.005		000
5699.106		0000 N	5710.144		00
5699.530	A	0	5711.016	A	000
5699.638		000	5711.313 s	Mg	6
5699.805	A	0000	5711.615	A	000 d
5700.402		00	5711.760	A	000
5700.508	Cu?	00	5712.098	Fe	3
5700.738		000	5712.357	Fe	2
5700.938	A	0	5712.620		000
5701.131		0000 Nd?	5712.835	-, A?	000
5701.323	Si	1 N	5712.996	Cr	0
5701.544		0000	5713.436		0000
5701.772 s	Fe	4	5713.670		000
5701.961		0000	5714.120		000
5702.110	A	000 N	5714.276	A	000
5702.228		0000	5714.380	Fe	0
5702.360		0000	5714.620		0000
5702.543	Cr	0	5714.774		00
5702.754		0000	5714.959		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5715.116		0000	5727.873		00
5715.308 s	Ni-Ti, Fe	5	5728.096		0000 N
5715.540		0000	5728.319		0000 N
5715.689		000	5728.742	A	00
5716.040		000	5729.096	A-	00 d ?
5716.441		0000 N	5729.417		000
5716.671	Ti	00	5729.876	A	0
5717.186	A	000	5730.030	A	00
5717.523		0000	5730.116	A?	0000
5717.723	A	00	5731.075		0 N
5717.918		000	5731.252		000 N
5718.055	Fe	4	5731.437		00
5718.338		000 N	5731.535		00
5718.510	-, A?	000 N	5731.769		000
5719.154	A	00	5731.984 s	Fe	4
5719.208	A?	0000	5732.214		0000
5719.536	A?	0000	5732.335		0000
5719.795	A	1	5732.522		0
5719.931	A	000	5732.790	A	0000
5720.040		00	5732.948		000
5720.275		0000	5733.097		000
5720.568	A?	000	5733.306	A	00 Nd?
5720.666	Ti, A	0	5733.550		0000
5720.933		000	5733.722		0000
5721.115		0	5733.908	A	000
5721.267		0000	5734.106		0000
5721.930		00	5734.262	A?	000
5722.047	A	000	5734.571		0000 N
5722.170	A	0	5734.786		0
5722.397	A	000	5735.790	A	0
5722.721		000 Nd?	5735.923		00
5722.997		0000 N	5736.241		0000 Nd
5723.590	A?	000	5736.858		0000
5723.756		0000	5737.288		0
5723.885		000	5737.530	A?	000
5723.989		000	5737.688		0000
5724.107	A	0	5737.910	A, Mn	1
5724.313		000	5738.453		0
5724.683		00	5738.693	A?	000
5725.224		0000	5738.767		000
5725.517		0000	5739.084		0000 N
5725.880		000	5739.275	A?	000
5726.168	-, A?	000 Nd?	5739.458		0000
5726.519		0000	5739.698		0
5726.701		0000	5739.873		000
5726.918	A	000	5740.020	A?	000
5727.097	A	0	5740.195		0
5727.271	Ti-V	2 N	5740.369		0000
5727.505		0000 N	5740.582	A?	0000
5727.682		000 N	5740.825		0000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5741.088	A?	000	5754.308		000
5741.432	A?	000	5754.450	A-	0
5741.715	A?	000 N	5754.623	Fe	0
5741.927		0000	5754.881 s	Ni	5
5742.068 s	Fe	2	5755.133		000 N
5742.293		000	5755.370	A	000 N
5742.420	A	0	5755.585	A	000 N
5742.785	A,-	000 N	5755.701	A	000
5743.025		0000	5755.970	A	000
5743.182		0	5756.182	A	000
5743.410		00 Nd?	5756.410	A?	0000
5743.645		00	5757.037	Fe	2
5743.774	-, A?	00	5757.293	A	000
5743.961	A	000	5758.161	A	000
5744.153		00	5758.493	A	000
5744.416		0000	5758.654	A	000
5744.679		0000	5758.978		000
5744.995	A	000	5759.120	A	000
5745.165	A	00	5759.338	A	000
5745.290	A	000	5759.488		0
5745.491	A	000 N	5759.760		0
5745.706	A	000 N	5760.403		0000
5745.932	A	00	5760.572	Fe	1
5745.997	A	1	5760.748		000
5746.638	A,-	000	5760.914	A?	0000
5747.025	-A	000 Nd?	5761.052	Ni	2
5747.502	A	000	5761.305		000
5747.890		1	5761.485	-, A?	000
5748.075		000	5761.637		0000
5748.176	Fe	2	5761.800	A-	0
5748.380		000 Nd?	5762.062		0000
5748.576	Ni	2	5762.479	Ti	000 Nd?
5748.737		0000	5762.635	Fe	1
5748.941		0000	5762.840	A-	00 N
5749.110		000	5763.058		0
5749.513		00	5763.218 s	Fe	6
5749.850		000	5763.460	A	000
5750.270	A,-	000 N	5763.625	A,-	00
5750.427		0000	5766.080	A?	000
5750.723	A	000	5766.485	-A?	000
5750.852		0000	5766.550	Ti	0
5751.357		0000	5766.808		0000
5752.018	A	000 N	5767.358	A	0
5752.254 s	Fe	4	5768.225	A	000 N
5752.459	-A?	000 Nd?	5768.575	A	000 N
5753.105	A	000 N	5769.120		000 N
5753.344 s	Fe	5	5769.295	A,-	000
5753.610		000 N	5769.547		0
5753.860	-Cr	1 N	5769.692		0000
5754.193	A?	000 N	5769.900	A	0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5770.405	A	00 N	5782.313 } s		3
5770.714	A-	000 Nd?	5782.390 }	Cu?	3
5771.008	A	0000	5782.582		000 N
5771.382	A	000	5782.815		000 N
5771.595	A	000	5783.078		000 N
5771.820		00	5783.288	Cr	2
5772.040		0000 Nd?	5783.463		000
5772.364 s	Si	3	5783.697		0000 N
5772.630		000	5783.888		0000
5772.800	A	000	5784.080 s	Cr	3
5772.889		0000	5784.268		000 N
5773.155	A	00	5784.605		000 N
5773.363	A	00	5784.879	Fe	1
5773.718	A-	000 N	5785.036		000
5773.982		0000 N	5785.188	Cr	2
5774.250	Ti, A	0	5785.498	Fe	3
5774.457	A,-	00 N	5785.772		00 N
5774.761		0000 N	5785.952	Cr	1
5775.020		0000 N	5786.193	Ti, Cr	0 N
5775.304 s	Fe	4	5786.373		000
5775.521		0000	5786.747		000 Nd?
5775.833		0000	5786.964		0000 N
5775.969	A	0000	5787.235	Cr	00
5776.292	A	000	5787.488		000
5776.468	A,-	000	5787.941		000 N
5776.958	A,-	000 N	5788.141 s	Cr	4
5777.737		000 N	5788.305	A (O)	000
5777.975		000	5788.398	A (O)	00
5778.222		0000	5788.504	A (O)	000
5778.505		0000	5788.611	Cr, A (O)	00
5778.677	Fe	1	5788.755	A (O)	0
5778.890	-A	000 N	5788.865	A?	0000
5779.025	A?	000	5788.990	A (O)	00
5779.406		0000	5789.095	A (O)	00
5779.583	A	000	5789.210	A (O)	000
5779.778		0000	5789.418[1]	A (O)	0 d
5779.913		000	5789.565	A?	0000
5780.176	A	0000	5789.700	A (O)	000
5780.378	A	000	5789.850	A?	0000
5780.520		000	5789.978	A?	0000
5780.600		0	5790.071	A (O)	0
5780.825	Fe	2	5790.186	A?	0000
5781.024	Fe	0	5790.313	A (O)	0
5781.130	Cr, Ti	00	5790.407	-, A (O)	00
5781.288		0000	5790.581	A (O)	000
5781.400	Cr	0	5790.759	A (O)	000
5781.573		0000	5790.878	A?	000
5781.763		0000	5790.985	A (O)	00
5781.967	Cr	0	5791.174 } s	Cr	4
5782.138		000	5791.243 }	Fe	3

[1] Principal line in the head of the δ group (atmospheric oxygen).

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5791.405		000	5803.802		0000 N
5791.485	A (O)	00	5804.045		0000 N
5791.620	A?	0000	5804.254	Fe	1
5791.750	-, A	0	5804.479	Ti	0
5791.974		000	5804.681	Fe	0
5792.140	A (O)	00	5804.996		0000
5792.311	A?	0000	5805.198		0000
5792.405	A?	0000	5805.441 s	Ni	4
5792.829	A?	0000	5805.638		000
5792.984	A (O)	00	5805.840	A (O)	0
5793.005		000	5805.986	La	0
5793.085		0000	5806.261	A?	0000 N
5793.292		3	5806.510	A (O)	0
5793.610	A (O)-	000	5806.747		0000
5793.920	A?	000	5806.950 s	Fe	5
5794.137	Fe	2	5807.172	C?	0000
5794.375		0000 N	5807.309	C?	000
5794.562		0000	5807.465	C?	0000
5794.664		000 N	5807.809		0000 N
5794.839		0000 N	5808.015	A,-	0
5795.086		0000	5808.207		00
5795.212		000	5808.406	A?	0000
5795.508		0000	5808.526	A?	0000
5796.102		000	5808.781	A?	0000 N
5796.304 [1]	Ni, A (O)	0	5809.085	A (O)	00
5796.486		0000	5809.256		0000
5796.635		00	5809.439 s	Fe	4
5796.885		000	5809.670		000 N
5796.985		00	5809.741	A (O)	00
5797.263		0000	5809.830		000 N
5797.497	A?	0000	5810.090		000 N
5797.715	A (O)	00	5811.010		00
5797.815	Ti?	000	5811.823		000 Nd?
5798.077 s		3	5812.139	Fe	0
5798.220	A?-	000	5812.345		0000 N
5798.398 s	Fe, A (O)	4	5812.418		0000
5798.728	A,-	000	5812.616	A (O),-	00
5799.154	A?	0000	5812.719		0000
5799.382	A?	0000	5812.942		0000
5799.730	A?	0000	5813.060		000
5800.055	A	0000	5813.270	A (O),-	00
5800.185	A (O)	00	5813.553		0000 N
5800.443	A-	000 Nd?	5813.884		000
5800.844	-, A (O)	0	5814.228		00
5801.058	A,-	0000	5814.788		0000
5801.483		00 Nd?	5815.030	Fe	1
5801.965	A,-	000 N	5815.246		0000Nd?
5802.546	A?	0000 N	5815.441	Fe	0
5802.885	A (O)	0	5815.663		0000
5803.549	A (O)	0	5815.766		0000

[1] First line in the tail of the δ group (atmospheric oxygen) mixed with a solar line.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5815.870		00	5834.440	A (O)?	0000
5816.086		000	5834.756		000
5816.289		0	5835.070	-, A (O)?	0000 N
5816.481	-, A (O)	00	5835.325		0
5816.601 s	Fe	5	5835.475		000
5816.845		0000Nd?	5835.645		00
5817.057	A (O), Mn?	00	5835.800		000
5817.299		0	5836.360		0000 N
5817.593		0000	5836.990		000
5817.708		000	5837.425		000
5819.517		0000	5837.925	Fe	0
5819.779		0000 N	5838.225		000
5820.145		00	5838.378		00
5820.510	A (O)	000	5838.592	Fe	1
5821.110	A (O)	000	5838.770	A	000
5822.107		00 N	5838.896		00
5822.680		00 N	5839.154	-, A	0000
5823.079		000	5839.600	A	000
5823.388		000	5839.823		00
5823.575		0000	5841.050	A	000
5823.910		00	5841.405		000
5824.388		000	5842.600		000
5824.628		00	5842.756	A	00
5824.858	A (O)	000	5843.110		00
5825.511	A (O)	000	5843.438		00
5825.975		00	5843.869	A?	0000
5826.328		0000	5844.057	A?	0000
5826.545		000	5844.405	A?	000
5826.860		000 N	5844.828		00
5827.299		0000	5845.140		00
5827.597		000	5845.509		0
5827.689		00	5845.696	A	000
5827.897	-A	000	5845.965	A?	0000
5828.097		0	5846.185		00
5828.460	A	000	5846.487		00
5828.979		0000 Nd?	5846.789		0000
5829.533	-, A (O)?	0000 N	5847.016		0000
5830.198		0000	5847.221	Ni	1
5830.305	A (O)	000	5847.477		0000
5830.895		000	5847.775		0000Nd?
5831.468	A (?)	0000	5848.105		0000Nd?
5831.821	Ni	1	5848.342	Fe	3
5831.967		000	5848.662		0000
5832.155		000 N	5848.888	A	000
5832.490		000 N	5849.187		000
5832.691		000	5849.415		000
5833.188		0000	5849.909		0
5833.886		0000 N	5850.145		000
5834.145		000	5850.320		000
5834.251		0	5850.553	A	0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5851.025	A	00 N	5865.027	A	000
5851.220	A	000	5865.109		0000
5851.427		0	5865.633	A (wv)	000
5852.005		0000 N	5865.852	A (wv)	00
5852.223		0000 N	5866.068	A (wv)	000 }
5852.443	Fe	3	5866.172	A (wv)	000 }
5852.789		000 N	5866.363	A (wv)	000 }
5853.378		0	5866.483		000 }
5853.538		000	5866.675	Ti	3
5853.690		000 N	5866.857		0000
5853.902 s	Ba?	5	5866.959		0000
5854.168	A	0000	5867.221		0000
5854.327	A?	0000	5867.302		00 N
5854.535		000	5867.550		000 N
5854.811	A,-	000	5867.785	Ca	2
5855.060	A	000	5868.010		0000
5855.300	Fe	1	5868.132		0000
5855.476		0000	5868.362		0000
5855.567	A?	0000	5868.507		0000
5855.755		0000 Nd?	5868.988	A	00 N
5856.105		0000	5869.320		0000
5856.312	Fe	2	5869.566	A	0000
5856.645		0000 N	5869.888	A	000
5856.838		0000	5870.008	-A (wv)	00
5857.674 s	Ca	8	5870.864	A (wv)	1
5857.976	Ni	3	5871.103		0000
5858.205		000 N	5871.365	A (wv)	000
5858.495		00	5871.523	A (wv), -	0
5858.750		000 N	5872.000	A	000
5859.001		0	5872.247	A	000
5859.215	-, A	000 N	5872.427	A	000
5859.463		000	5872.490	A?	0000 N
5859.620		0000	5873.343		0000
5859.809 s	Fe	5	5873.436		1
5860.176		0000	5873.630		0000
5860.306	A?	0000	5873.790	A (wv)	0
5861.331		0	5873.988		00 N
5861.845	A (wv)[1]	0	5874.175	A (wv)	000
5862.021	A	000	5874.697	A?	0000
5862.582 s	Fe	6	5874.865	A (wv)	000
5862.817		0000	5874.995		0000 N
5863.075		000 N	5875.360	A (wv)-	00 N
5863.380	A	000	5875.660	-, A?	0000
5863.685	A	000	5875.815	A (wv)	0
5863.933		0000	5875.985	-, A (wv)	0000 N
5864.167		000	5876.338	A (wv)	1
5864.268		0000	5876.514		00
5864.463		0	5876.664	A (wv)	0
5864.575	A	000	5876.770		0000
5864.742		0000	5877.027		0000

[1] A (wv) stands for an atmospheric line due to water-vapor.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5877.273	A	000	5885.973	A?	0000
5877.547	A (wv)	00	5886.193	A (wv)	5
5877.640		0000 Nd?	5886.390		0000
5877.780	A (wv)	000	5886.560	A (wv)	1
5877.903		0000	5886.620	A (wv)	0
5878.015		0	5886.905	A (wv)	0
5878.245		000 N	5887.045	A	000
5878.504	A	0000	5887.445	A (wv)	5
5878.790		0000 N	5887.690		000
5879.225	A	0000 N	5887.880	A (wv)	3
5879.417	A (wv)	00	5888.056	A (wv)	00
5879.506		0000	5888.404		0000
5879.715		00	5888.655		0000
5879.820	A (wv)	1	5888.920	A (wv)	2
5879.945	A (wv)	1	5889.110		0000
5880.035		0000	5889.303	A (wv)	00
5880.250		0 N	5889.587		0000 N
5880.490		00	5889.855 s	A (wv)	3
5880.649		0000	5890.100 [1]	A (wv)	2
5880.725	A (wv)	00	5890.186D_2s[2]	Na	30
5880.832		0000	5890.425	A (wv)	0
5880.948	A (wv)	0	5890.529		000
5881.147	A (wv)	1	5890.720		00 Nd?
5881.320	A (wv)	0	5890.950	A (wv)	00 Nd?
5881.500		0	5891.125	A?	0000 Nd?
5881.636	A	000	5891.398	A (wv),–	1
5881.760		0000	5891.581		0000
5881.940		000	5891.720	A (wv)	0
5882.084	A (wv)	1	5891.878	A (wv)	4
5882.203	A (wv)	0	5892.108		000
5882.412	A	0000 N	5892.271	A?	0000
5882.589	A	000	5892.493	A?	0000
5882.708	A	000	5892.608	A (wv)	3
5883.025	A (wv)	0	5892.690		000
5883.218	A (wv)	00	5892.920	Fe	00
5883.285		000	5893.097s	Ni	4 d?
5883.529		0000	5893.268	A (wv)	0
5883.589	A?	000 N	5893.455		000
5883.655		0000 N	5893.725	A (wv)	1
5883.790		0000 N	5894.050	A?	0000
5884.028 } s	Fe	4	5894.360	A?	0000
5884.120 }	A (wv)	5	5894.605	A (wv)	0
5884.245		0000	5894.820	A (wv)	0000 N
5884.410	A (wv)	0	5895.162	A (wv)	0
5884.655		000	5895.360	A (wv)	0
5884.960	A	000	5895.582		0000
5885.278		00	5895.901		00 N
5885.596		000	5896.155	Na	20
5885.733	A (wv)	000	5896.35D7$_1$s[3]		00 N
5885.840	A (wv)	00	5896.506		000

[1] This line is coincident with the edge of D_2 toward the violet and is therefore very difficult to see.

[2] The width of D_2 is 0.175. The width of D_1 is 0.160.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
5896.635	A (wv)	0	5905.148		0000
5896.710	A (wv)	1	5905.335	A (wv)	00
5896.857		0000	5905.505	A (wv)	0
5897.047	A (wv)	2	5905.583	A (wv)	00
5897.300	A (wv)	00	5905.652		0000
5897.400		0000	5905.745	A?	0000
5897.470		00	5905.895 s	Fe	4
5897.677	A (wv)	0	5906.130	A?	0000Nd?
5897.750		000	5906.390	A (wv)	000
5897.970	A (wv)	00	5906.505	A (wv)	000
5898.160	A (wv)	00	5906.733		000
5898.378 } s	A (wv)	4	5906.864		0000
5898.430 }		00	5907.060		0
5898.615	A (wv)	000	5907.220	A (wv)	00
5898.745		0000	5907.475	A (wv)	0
5898.980	A (wv)	00	5907.574	A (wv)	000
5899.011	A?	0000	5907.692	A (wv)	00
5899.215	A (wv)	2	5907.873		0000
5899.315		0000	5908.070	A (wv),–	1
5899.518	Ti	1	5908.258	A?	0000
5899.752	A (wv)	00	5908.425	A (wv)	1
5899.887		000	5908.640	A?	0000
5900.135	A (wv)	2	5908.795	A?	0000
5900.260	A (wv)	4	5908.945		0000
5900.585	A?	0000	5909.020		0000
5900.648	A (wv)	000	5909.213	A (wv)	3
5900.981	A?	0000	5909.395		0000
5901.140	A (wv)	00	5909.668	A (wv)	00
5901.296	A?	0000	5909.878	A?	0000
5901.465	A (wv)	00	5910.060	A?	0000
5901.682 } s	A (wv)	6	5910.197	Fe	1
5901.745 }		00	5910.398	A (wv)	1
5901.926		0000	5910.528	A (wv)	000
5902.028		0000	5910.700	A (wv)	00
5902.238	A (wv)	000 N	5910.855	A (wv)	00
5902.363	A (wv)	1	5910.987	A (wv)	2
5902.465		000	5911.140	A (wv)	000
5902.694	Fe	0	5911.365		0000
5902.870	A?	0000	5911.435	A (wv)	000
5903.035	A (wv)	000	5911.710	A (wv)	000
5903.334		0000	5911.810	A?	0000
5903.555		00	5912.093	A (wv)	00
5903.748	A (wv)	1	5912.228	A (wv)	00
5903.918	A (wv)	00	5912.345		000
5904.070	A (wv)	00	5912.757	A (wv)	000
5904.160	A (wv)	00	5912.918	A (wv)	0
5904.420	A?	0000	5913.212	A (wv)	3
5904.592	A (wv)	000	5913.358	A?	0000
5904.850	A?	0000	5913.570		0000
5905.050	A?	000	5913.930	A?	000

THE MODERN SPECTROSCOPE. XIV.

FIXED ARM CONCAVE GRATING SPECTROSCOPES.

By F. L. O. WADSWORTH.

THE invention of the concave grating by Professor Rowland in 1881 marks one of the most important steps in the history of spectrometry. The many advantages which this beautiful instrument possesses over all other forms of diffraction spectroscopes is leading naturally to its more and more exclusive use in nearly all classes of work to which such spectroscopes are applicable, with one important exception, *i.e.*, that of astronomical spectroscopy.

This exception is the more surprising since it is in this very class of work that some of the peculiar advantages of the concave grating over the plane grating are most manifest; for example, its astigmatism, which renders the use of a cylindric lens at the eyepiece unnecessary in star work; and the very short focal lengths and large angular apertures which may readily be secured, making it peculiarly adapted to short focus reflectors which are undoubtedly the form of telescope best suited to stellar spectroscopy.

One reason why the plane grating is preferred to the concave grating for astronomical spectroscopes is, no doubt, that the usual form of mounting for the latter is not well adapted to this work. In the ordinary laboratory use of the instrument nothing can be more simple and satisfactory than the sliding-bar arrangement, originally designed by Rowland, which has since come into almost universal use in the mounting of these instruments. But in an astronomical spectroscope it is important that all parts of the instrument, save the grating table itself, should be fixed in position, not only to secure rigidity for all positions of the telescope, but also to enable the parts to be completely

enclosed and protected from stray light and air currents in the dome. In certain other kinds of work also, notably that with the bolometer, radio-micrometer, and refractometer or Michelson "interferometer," the "fixed arm" form of instrument is essential if the best results, as regards both accuracy and simplicity and convenience, are to be secured. The plane grating is from the very method of its use essentially an instrument of this kind, and the ordinary prism train can easily be converted into one by use of a reflecting mirror in one of the various ways that have been discussed by the writer.[1] But in the case of the concave grating no corresponding arrangement has to my knowledge been proposed.[2]

It was while working on the forms of fixed-arm prism spectroscopes just spoken of that I first considered the problem of obtaining an equivalent form of mounting for the concave grating. The conditions to be fulfilled are the same in both cases, *i.e.*, a fixed position of source (not necessarily however a fixed slit), and a fixed eyepiece, the latter to be always normal to the grating, or at least to the focal plane of the spectrum at the point under examination, in order that all the lines in the field may be in focus at once. The fulfillment of this latter condition involves no difficulty in the case of the prism train or plane grating where the refracted or diffracted rays are always brought to a focus by a view telescope whose direction and focal length remains unchanged. But in the case of the concave grating, the direction of the diffracted ray and the distance of the grating from either the slit or the observing eyepiece must *both* vary for each

[1] "An Improved Form of Littrow Spectroscope." *Phil. Mag.*, July, 1894. "Fixed Arm Spectroscopes." *Phil. Mag.*, Oct., 1894., *A. and A.*, Dec., 1894. "Some New Designs of combined grating and Prismatic Spectroscopes of the Fixed Arm Type." ASTROPHYSICAL JOUR., March, 1895. "A New Multiple Transmission Prism." ASTROPHYSICAL JOUR., Nov., 1895.

[2] The interchange of the usual position of slit and eyepiece in the Rowland mounting, as made by Mr. Lewis in his recent work with the radio-micrometer (see this JOURNAL June, 1895), enables, it is true, the observing instrument to be fixed in position, but this only solves one half the problem, for it would of course be impossible to use this arrangement with a fixed source of light, the Sun or a star, for example.

wave-length, and this double variation introduces additional complexity in a design of a fixed-arm form of mounting for this instrument. I have not yet succeeded in finding as simple and complete solution of this problem as was found in the case of the prism train, although I have designed a large number of forms in which all of the above conditions are fulfilled. On account of the desirability of using the concave grating in the classes of work above referred to I have thought that it might be of interest to describe some of the more promising of these, but I hope that some one may be able to suggest improvements in the direction of greater simplicity and compactness, for I am not fully satisfied in these respects with what I have so far been able to produce.

Let us first consider the possible relations between the radius of curvature of the grating ρ, the distance of the slit from the grating R, and the distance of the focal image from the grating r. The general equation between these quantities is

$$r = \frac{\rho R \cos^2 \theta}{R(\cos\theta + \cos i) - \rho \cos^2 i}, \tag{1}$$

where i is the angle of incidence and θ the angle of diffraction.

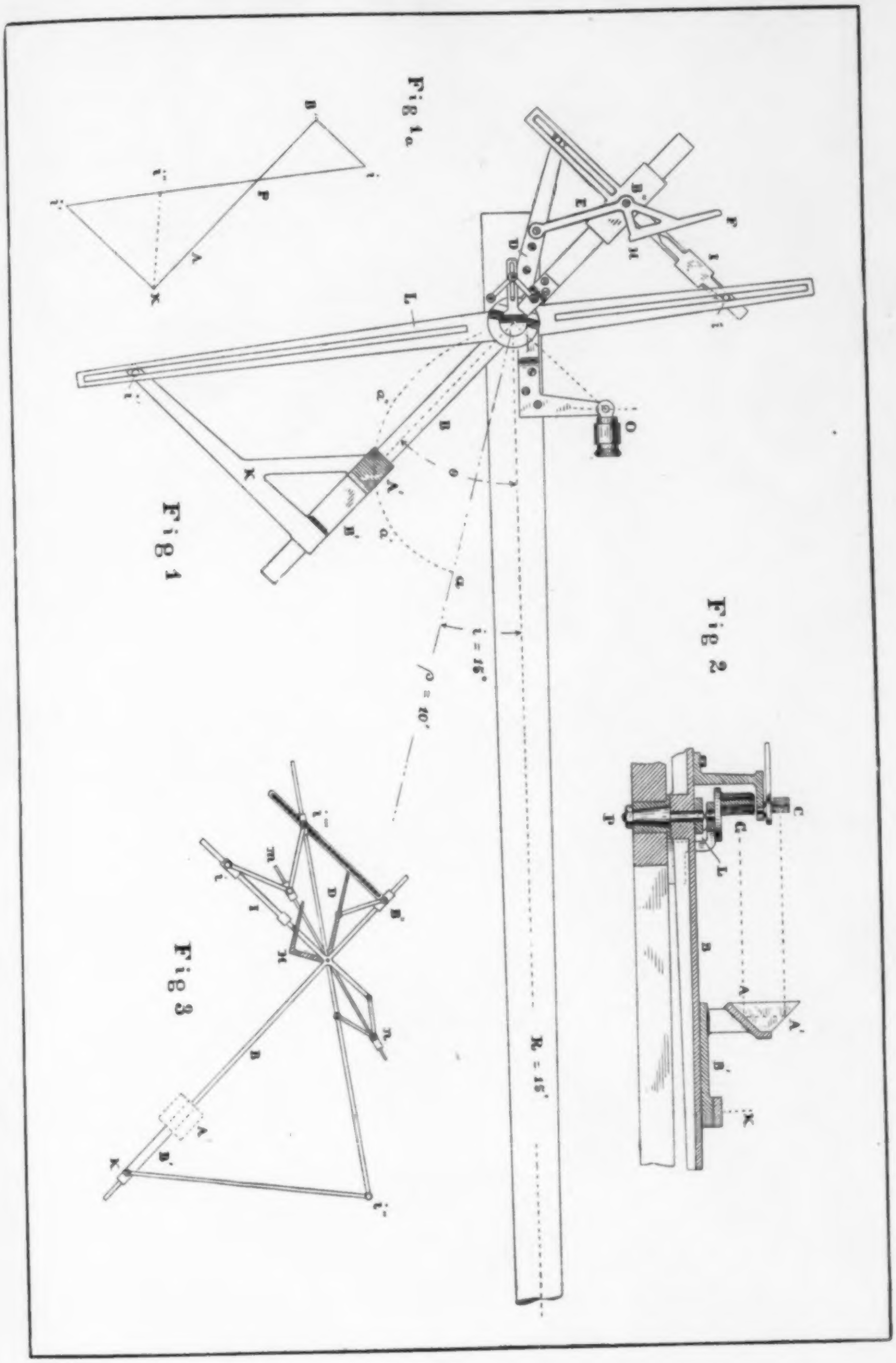
This equation represents, as has been shown by Professor Rowland, a pair of conjugate curves, of which the coördinates are respectively r and θ and R and i. If these last two quantities be fixed, *i. e.*, if we start with a fixed position of the slit and a fixed position of the grating, then we have for r:

$$r = \frac{\rho R \cos^2 \theta}{R\cos\theta + (R - \rho\cos i)\cos i} = \frac{\rho\cos\theta}{1 + a\sec\theta}, \tag{2}$$

where $a = (1 - \frac{\rho}{R}\cos i)\cos i = \text{Const.}$

To obtain a fixed-arm form in this case we may make use of the arrangement shown in Plate XIII, Figs. 1 and 2. The diffracted ray is received on a doubly reflecting prism or pair of mirrors, A, A', which is carried on an arm B, pivoted at P just below the center of the grating G. From A' the ray returns to a second mirror C, placed just above the grating. This mirror is carried on a table, which rotates on an axis concentric with P, and is connected to the arm B,

PLATE XIII.



as shown in Fig. 1, by the usual form of minimum deviation device (or better that described on p. 345, *Phil. Mag.*, 1894), so as to move in the same direction as the latter, but at one-half the angular velocity. From C the diffracted ray is therefore reflected in a constant direction, CO, to the observing eyepiece at O. As the angle θ is changed, the distance $GAA'CO$, must be kept equal to r, in order that the spectrum remain in focus at O. To do this we must keep the distance GA equal to a quantity x, which is evidently equal to $\frac{1}{2}[r-(OC+AA')]$,

or $$x=\frac{1}{2}\frac{\rho\cos\theta}{1+\alpha\sec\theta}-\frac{\beta}{2}, \qquad (3)$$

where α and β are constants.

This may be accomplished by mounting the prism AA' on a carriage B' which slides along the arm B. The position which the prism would have to occupy for different values of θ is easily calculated from (3), when we know the values of ρ, R, i and β. In the case of the particular values adopted in Fig. 1 it is shown by the dotted line $a\,a'\,a''$. The adjustment of the carriage to this curve might be accomplished automatically by means of a cam of the form $a\,a'\,a''$, or by the system of link work shown in Fig. 1 or in Fig. 3. In Fig. 1 D is an arm fixed in position normal to the grating and equal in length to $\frac{1}{10}\,\rho$. Pivoted to its outer end is a second link E equal to it in length, and having its free end pivoted to a carriage B'', which slides on the arm B. Attached to the outer end of E, and forming part of it is the right-angled bar $B''HF$ of which the side HF is parallel to E, and at a distance $B''H=\alpha=(1-\frac{\rho}{R}\cos i)\cos i$ from its axis. Against this side rests a knife-edge attached to a slide I, which moves on an arm attached to B'' at right angles to B, and on this slide is a pin i placed at unit distance above the knife-edge. Attached to the carriage B', which carries the reflecting prism AA', is another arm K also at right angles to B, and having a second pin i' at a distance equal to $2'.5$ from the center line of B. A long link L, pivoted at P, and having two radial slots to receive the two pins i and i', completes the

arrangement. Then if the prism AA' is placed at a distance $AK = \frac{1}{2}\beta = \frac{1}{2}(AA' + OC)$ from the center of K the distance PA will always be equal to x as desired.

For, see (Fig. 1_a),

$$PB'' = \tfrac{1}{5}\rho\cos\theta, \text{ and } B''i = 1 + a\sec\theta,$$

$$\therefore \frac{PK}{2\frac{1}{2}} = \frac{PA + AK}{2\frac{1}{2}} = \frac{\rho\cos\theta}{5(1 + a\sec\theta)},$$

or

$$PK = \tfrac{1}{2}\frac{\rho\cos\theta}{1 + a\sec\theta} \text{ and } PA = x.$$

In the system of link work shown in Fig. 3 we have the same general arrangement of parts as in Fig. 1 save that instead of keeping the side $B''i$ of the right angled triangle $PB''i$, (Fig. 1_a), equal to $1 + a\sec\theta$, we keep the hypothenuse Pi equal to this quantity. This is accomplished by attaching the right angled lever FH not to the end of link E but to the inner end of the fixed link D. The slide I moves on an arm fixed at right angles to B at the center, and its motion is communicated to a second slide i''' moving on the arm L, by means of the sliding-toggle links shown in the figure. The slide i''' has a pin which engages with a slot cut in an arm extending out from the carriage B'' at right angles to B and the bar PB'' and arm L therefore always form the base and hypothenuse respectively of the corresponding right angled triangle of Fig. 1_a. Hence if we place a pin at i'' on the bar L at a fixed distance $= 2.5$* from P and connect this to the point K on the carriage B' by a link $i''K$ of the same length as $i''P$, the side PK or the distance of the point K on the carriage from the axis of rotation will always be equal to $\frac{1}{2}\frac{\rho\cos\theta}{1 + a\sec\theta}$ as before.

If instead of varying θ and r we vary i and R, we obtain a precisely similar arrangement, in which the slit s and the observing eyepiece O have simply been interchanged. This arrangement is in some respects preferable to the first, because all reflectors are between the slit and the grating, instead of between the

*Since the hypothenuse must always be greater than the side PB'' it is necessary to make the links D and E of such length that $D + E$ is less than $1 + a$. In the figure D and E are therefore $\frac{1}{2}$ as long as in Fig. 1 or are each $\frac{1}{20}\rho$.

latter and the observing eyepiece. A still more important advantage is that we may dispense with the mirror C and place the slit directly over the axis of rotation P. If the illumination were symmetrical about this axis nothing further would be necessary, but usually the light comes from a source S in the fixed direction SC, Plate XIV, Fig. 4. In order that the grating may be filled with light it is necessary that the rays should always fall on the slit from the direction $C's$ coincident in direction with GA, and to secure this the mirror C is placed just at one side of the slit on a frame which rotates on the axis P at one-half the angular speed of the slit arm B. This mirror, therefore, is always in a position to reflect the rays from S to the concave mirror C', which is mounted on the slit arm itself, and which in turn forms an image of the source on the slit plate. Since the rays are not reflected at the axis of rotation, there will be a slight lateral displacement of the image on the slit plate as the arm B revolves, but this may be avoided if objectionable by inserting a collimating lens between S and C, so as to render the beam incident on C parallel.[1] As before AA' must be moved along B as the latter revolves, in order to keep the spectra in focus at O. This may be done automatically by one of the preceding systems of link work, which is omitted from Fig. 4 for the sake of clearness.

Let us now examine the effect of rotating the grating itself on the axis P, all of the other parts of the spectroscope remaining fixed in position, just as in the use of the plane grating. In this case i and θ vary together, and if we call ϕ the fixed angle between the line of collimation Gs and the direction of the diffracted ray GO, we have

$$\theta = \phi - i,$$

and

$$R = \frac{\rho \cos^2(\phi - i)}{\cos(\phi - i) + \left(1 - \frac{\rho}{r}\cos i\right)\cos i}$$

$$= \frac{C\cos^2 i + C_1 \sin^2 i + C_2 \sin 2i}{C_3 \cos i + C_4 \sin i - C_5 \cos^2 i} = f(i), \qquad (4)$$

[1] The theory of this mirror mounting has been already discussed in one of the articles above referred to. See *Phil. Mag.*, **38**, 342.

where C, C_1, C_2, . . . C_5 are all constants depending for their numerical value on the values of R, ρ, and β.

In this case to keep the spectra in focus as the grating revolves we would have to vary either the distance Gs or GAO, so as to keep it constantly equal to R. We might do this just as before by using a doubly reflecting prism in the path of one of the rays and moving this prism by an amount equal to ½ the change in R. Since both the directions GO and Gs are in this case fixed, no other reflectors are required, and the arrangement becomes in that respect simpler than either of the preceding. We might indeed dispense with all reflections, and simply move the slit S along the line of collimation, for as this remains fixed the direction of the incident light will also remain fixed, and to keep the image of the source on the slit all that is necessary is to attach the condensing or image-forming lens to the same carriage that carries the slit, and move the two together.

This last arrangement could not, of course, be used in case the position of the image is fixed, as in an astronomical spectroscope. In this case, although the arrangement of parts is simpler than in the two preceding cases, the arrangement necessary to keep the distance Go or Gs automatically equal to R would be very complicated if link work were to be used.

The most practical way to secure the required motion of the prism AA' or the slit S would be to attach to the grating a cam of the form $r' = \frac{1}{2}f(i) - \frac{\beta}{2}$, or $R = f(i)$ respectively, the values of $f(i)$ being calculated from (4). Such an arrangement would, of course, only work for one particular set of values of r, ϕ, and β, and in order to avoid making this cam very large it would be necessary to make r considerably greater than ρ and β also large. Such a cam calculated from (4) for the values $\rho = 10$, $r = 15$, $\phi = 15°$, and $\beta = 2$ as before, is shown in Fig. 5.

The preceding solutions are perfectly general in character, *i. e.*, they hold good for all values of R, r, θ, and i. They are, however, of theoretical interest rather than of practical importance on account of the mechanical complexity of the mountings.

PLATE XIV.

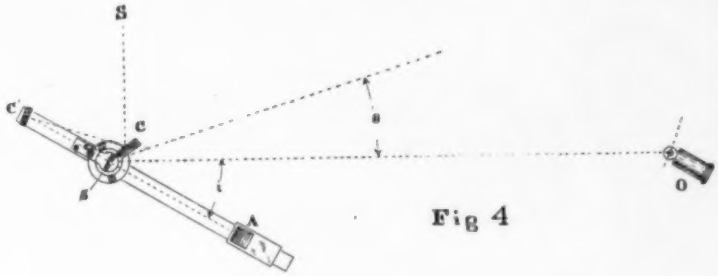


Fig 4

Fig 5

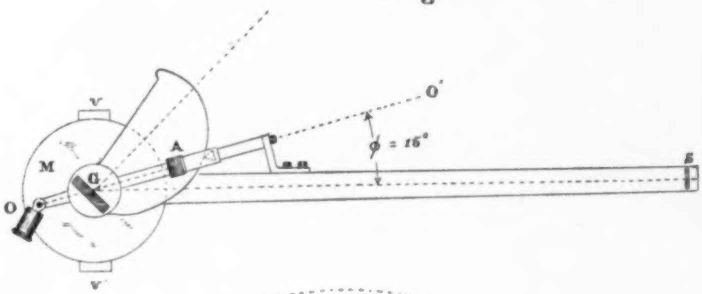
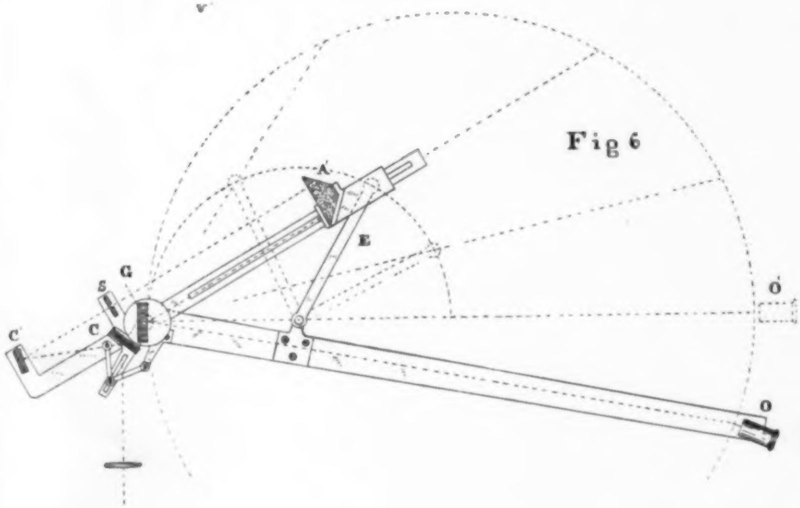


Fig 6



We will now proceed to consider some special solutions which lead us to better mechanical designs. Naturally the most simple relation between r and θ, or R and i, is obtained by making $R = \rho \cos i$, as in Rowland's mounting. Equation (1) then becomes

$$r = \rho \cos \theta,$$

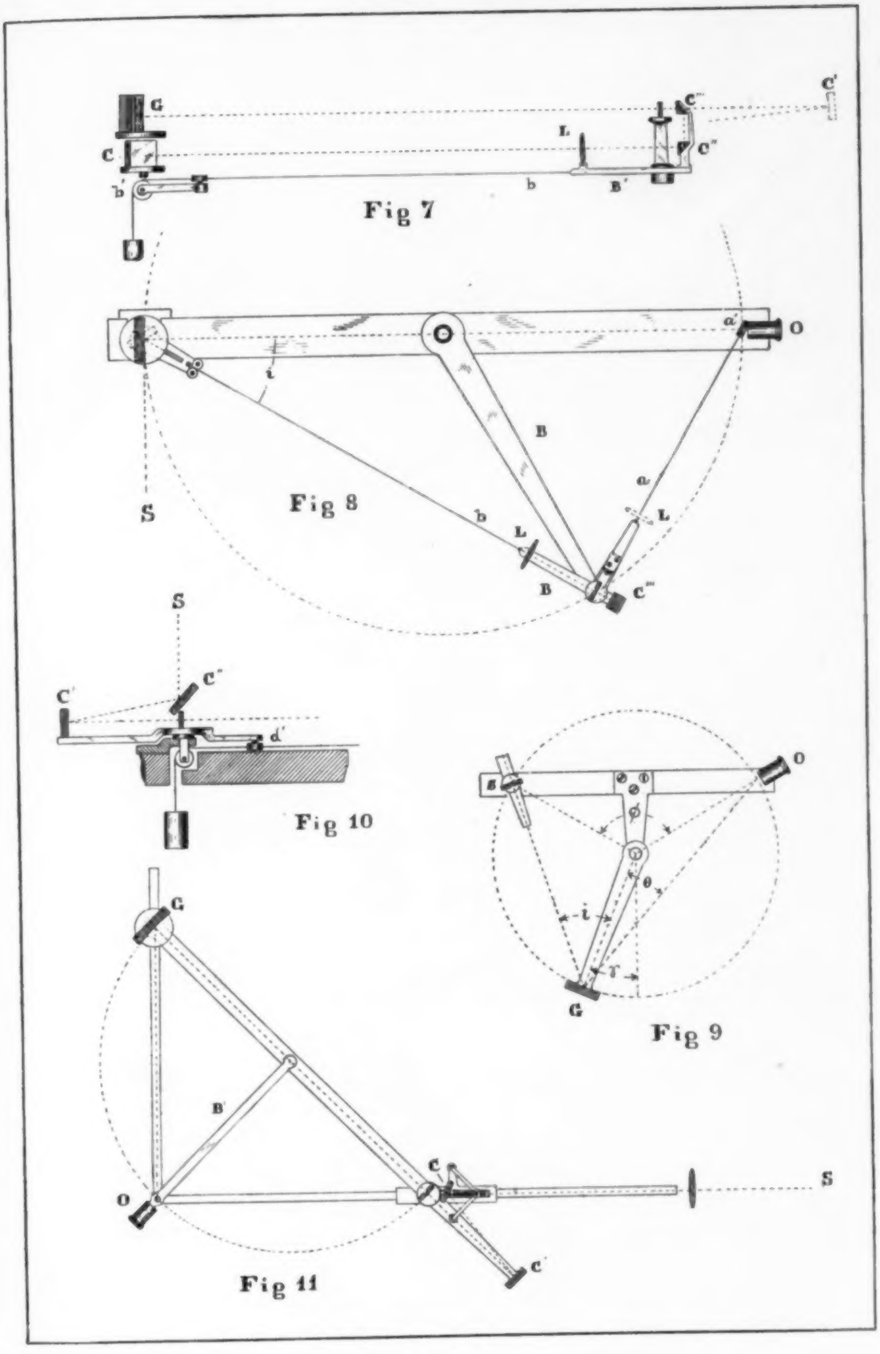
and the spectra lie on the circumference of a circle of a diameter equal to the radius of curvature of the grating. For this special case there are three forms of fixed-arm mountings which correspond to the three general solutions treated above, *i. e.*, those in which the direction of the diffracted ray varies, those in which the direction of the incident rays is varied, and those in which the directions of both incident and diffracted rays are varied together by a rotation of the grating. The first two forms are conjugate and are obtained from each other by simply interchanging the position of the slit and eyepiece. It will, therefore, be necessary to describe only two types of the second class, *i. e.*, those in which the angle of incidence is changed by the virtual or actual movement of the slit. As has already been stated, these forms are generally preferable to those in which the eyepiece or its virtual image is moved. Fig. 6 shows a mounting for this special case corresponding to the general mountings of Figs. 1 and 4. The reflecting prism or pair of mirrors may be placed either in a vertical plane or in a horizontal plane, as shown in this figure, and must be automatically maintained at a distance x from the grating, equal to $\frac{\rho}{2} \cos \theta - \frac{\beta}{2}$, where $\beta = AA' + G s$, as before.

This is very easily accomplished in this case by a single link E, which is of a length $\frac{\rho}{4}$ and is pivoted at one end to the carriage which carries the reflecting system and at the other on a line normal to the grating and at a distance $\frac{\rho}{4}$ from it. The reflector is then mounted on the carriage at a distance $\frac{\beta}{2} = \frac{1}{2} (AA' + G's)$ from the pivoted end of E, which must move, as is readily seen, in a circle of radius $\frac{\rho}{4}$. This corresponds to a movement

of a virtual image of s on the circumference of a circle of diameter ρ and thus satisfies the conditions for keeping the spectra in focus at O. The eyepiece at O is placed normal to the circumference of the circle at that point and evidently always remains normal to the spectrum. It may, of course, be placed anywhere on the circumference of the circle, but its best position for micrometric or photographic work is diametrically opposite the grating, or at O'. In order to keep the image of a fixed source S always on the slit, a mirror C moving at half the angular velocity of B, and a condensing mirror C', mounted on B, is used as in Fig. 4.

By arranging the mirrors $A A'$ in a horizontal instead of a vertical plane, one important advantage is gained, *i. e.*, an angular displacement of the system by reason of want of straightness in the ways on which the carriage slides has no effect upon the direction of the doubly reflected ray, which therefore can always be accurately determined by the angular reading of a divided circle connected to the arm B. But we can do away with all reflectors inside the spectroscope train by mounting the slit s directly on the end of an arm of length $\frac{\rho}{2}$ pivoted not at the center of the grating but at the center of the circle on which the grating and the observing eyepiece lies (see Plate XV, Figs. 7 and 8). In this last the direction of the light is kept right by mounting the slit, the two reflectors C'' C''' and a condensing lens L on a short par B' pivoted on the end of B and kept directed towards the grating by means of a steel cord $b\,b'$ attached to its end and passing over a pulley just under the center of G; the cord being kept taut by means of a heavy weight. To keep the arm more perfectly in balance a second cord $a\,a'$ may be attached to an arm at right angles to B' and led over a pulley diametrically opposite to the first one. The light from the fixed source S is kept directed upon the lens L by means of a mirror C which is placed between the grating and the pulley b' and moved at the required angular speed by the usual minimum deviation link work, the movable arm of which is kept directed by the cord $b\,b'$ as shown. Instead of this arrange-

PLATE XV.



ment we might use a single condensing mirror at C', or equally well a right-angled prism just behind the slit, a condensing lens at L', and a movable mirror just above the pulley a' and just below the eyepiece O.

In the second class of mountings both slit and eyepiece are fixed at two particular points on the circle, and the grating revolves. Here the conditions are best fulfilled not by revolving the grating on its own axis, as in the general solution, but by moving it along the circumference of the circle of diameter ρ. This is accomplished by mounting it normal to a radius arm of length $\frac{\rho}{2}$. The only mechanical problem in this case is to keep the light from the slit automatically directed towards the grating. This may be simply done by an arrangement very similar to that in the preceding figure by mounting the slit and the condensing mirror C', Figs. 9 and 10, on a short arm pivoted just below the slit and kept in line with the grating by a steel cord attached to the latter and passing first between two guide pulleys d' on the end of the arm and then over a pulley mounted in the axis of rotation. The light is kept on the condensing mirror C' by a mirror C mounted at one side of the slit as in Fig. 4; or, by means of a mirror C'' mounted as in Fig. 10 just above the slit and revolving with it. In case the light can be made to come from a direction parallel to the axis of rotation, or conversely, if the axis of rotation can be made parallel to the direction of the light, this same arrangement may be adopted with advantage in any of the preceding mountings, thus dispensing with any minimum deviation movement for the reflecting mirror C.

The relation between wave-length and angle of rotation of the grating arm is in this case very simple.

We have

$$\frac{n\lambda}{s} = (\sin i - \sin \theta).$$

But if we measure the angle of rotation from the position in which the arm is perpendicular to the line joining the slit and eyepiece, *i. e.*, the position in which the central image of the slit

coincides with the cross wire, then, since G, s and O all lie on the circumference of a circle $i+\theta=$ Const.; and if we call ϕ the angle subtended at the center of the circle by the chord sO joining slit and eyepiece, we have

$$i=\tfrac{1}{2}\left(\frac{\phi}{2}+\gamma\right)$$

$$\theta=\tfrac{1}{2}\left(\frac{\phi}{2}-\gamma\right),$$

and

$$\frac{n\lambda}{s}=2\cos\frac{\phi}{4}\sin\frac{\gamma}{2}=\text{Const.}\sin\frac{\gamma}{2}.$$

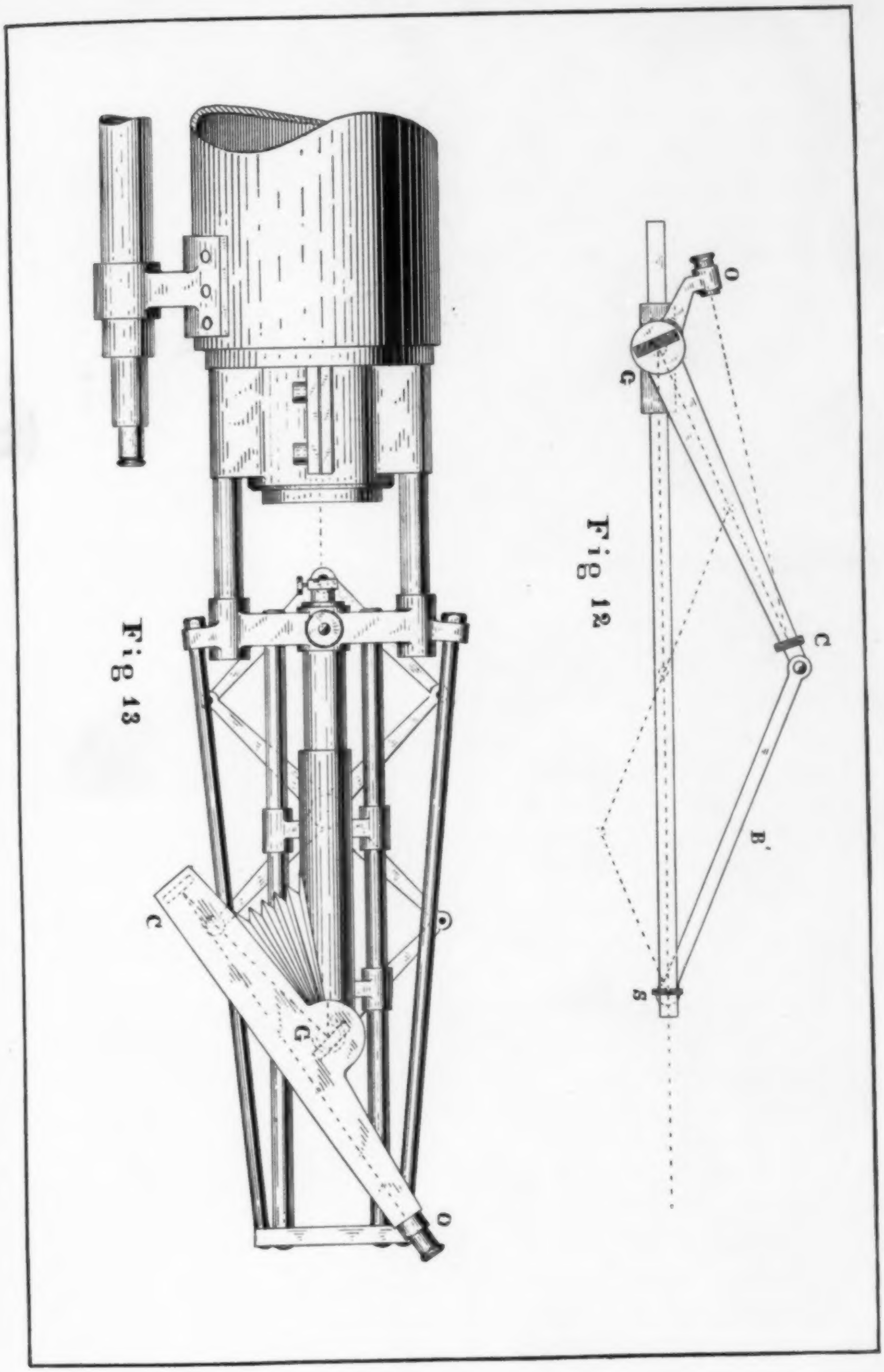
The range of spectra depends on the value of $2\cos\frac{\phi}{4}$ or on the distance of the slit from the eyepiece, the range becoming greater as ϕ becomes smaller.

A second mounting of this class is shown in Fig. 11. It is similar in general outline to the form adopted by Lewis in the work referred to in a previous footnote. The positions of the slit and eyepiece are simply interchanged in an ordinary Rowland mounting. In order to keep the latter always normal to the spectrum it is mounted on the radius arm B', pivoted at one end at the intersection of the two arms of the mounting and at the other to the middle of the grating bar Gs. The light comes from a source S placed at the end of the track OA and is kept upon the condensing mirror C' by means of a plane mirror C mounted so as to rotate on an axis concentric with the pivot on which the grating arm turns and connected to the latter by the usual form of minimum deviation attachment, as shown.

Of these various forms those shown in Figs. 5, 6, 8 and 11 are perhaps the most satisfactory, from both a mechanical and an optical point of view. The first three general solutions are, as already remarked, of theoretical rather than practical importance.

There is one other form of mounting which, although it does not satisfy all the conditions of a fixed-arm arrangement, is worthy of mention in this connection, both because of its compactness, which enables a concave grating to be mounted in a considerably smaller room than is required with the usual mounting, and because from its form it is very well adapted to astro-

PLATE XVI.



nomical spectroscopes. It is derived directly from the usual Rowland arrangement by adding the radius arm B', as in Fig. 11, and mounting on the grating arm a plane reflector C which returns the diffracted rays to an eyepiece O placed just at one side of the grating and moving with it (see Plate XVI, Fig. 12). The outer half of the grating arm together with the usual eyepiece carriage and track may then be dispensed with. It is evident that, with this arrangement, the slit, grating and observing eyepiece maintain the same relative position to one another as in the ordinary mounting, and that all the spectra may be brought in succession into the field by sliding the grating carriage along the bar Gs. Or the same result may be secured by fixing in position the pivot on which the grating bar turns, and sliding the slit (and an attached condensing lens) along the same bar. In either case the eyepiece is not fixed but travels on the circumference of a small circle, whose center is in the axis of the grating pivot. The range of motion, however, is small and the eyepiece is always in a convenient position for observation. Other advantages of this form of mounting are that the lateral space required is only one-half as great as with the usual form of mounting and, therefore (since the angle rarely needs to exceed 60°), a 21-foot grating may be mounted in a room not more than 22×10 feet; that the grating may be used for smaller values of θ than the usual mounting permits of; and finally, that it may be swung right up to and through the zero position, and the spectra on both sides brought into the field with equal ease without reversing the grating on its mounting. It is also evident that the optical parts may readily be completely enclosed (provided the spectra on one side only are used). The principal disadvantages are the length of the links GC and B' and the fact that both overhang their respective centers. We may, however, easily overcome both of these difficulties, the first by bisecting each of the links GC and B' and pivoting the ends of the short links thus obtained to a third link of length equal to B', but itself pivoted at the center on a slide which moves on Gs (see dotted lines on Fig. 12). It is evident that the relative motion of the grating arm with respect to the slit will be the same as before.

To overcome the second difficulty it is only necessary to place the reflecting mirror *C* nearer the grating, say at a distance $= \frac{1}{3}\rho$, and then extend the grating arm an equal distance on the other side of its axis to carry the eyepiece or photographic plate, as in Fig. 13.

The advantages just enumerated make this form of mounting particularly well adapted to an astronomical spectroscope, one design for which is shown in Fig. 13. In this the last system of three links between slit and grating are used and, in order to make the motion smoother and more accurate, the system has been doubled, producing the familiar lazy tongs mechanism. The inner end of the link work train is pivoted just under the slit and moves with it as it is adjusted to the focal plane of the telescope, and the outer end is pivoted on the grating axis. This axis carries the grating box *GCO*, containing the grating, reflecting mirror *C* and eyepiece or photographic plate at *O*. The box is connected light tight to the outer half of the collimator tube, to which are secured the ways on which the whole slides to and from the slit. The outer half of the collimator tube is made to slide freely, and yet light tight over the inner (slit) end by means of rings of felt. The range of motion is from $\theta = 10°$, corresponding for a 10,000-grating to wave-length 4400 in the first spectrum, to $\theta = 60°$, corresponding to about wave-length 22,000 in the first, or to about 5500 in the fourth order, a range sufficient for almost any purpose in view. It will be observed that the eyepiece is always clear of the grating track, and in a position favorable for observation with reference to the telescope, and it would be easy to design the mounting so that it might be used either for a concave grating as shown, or, by simply disconnecting the link-work, clamping the grating carriage in position, inserting a collimating lens in the collimator tube and replacing the plane mirror at *C* by a concave of focal length *CO;* for a plane grating or fixed-arm prism train similar to one of those shown in Figs. 2, 3, 4 or 5, Plates XII and XIII, of the March number of this JOURNAL.

RYERSON PHYSICAL LABORATORY,
University of Chicago,
November, 1895.

Minor Contributions and Notes.

NOTE ON HELIUM IN BETA LYRÆ.

In a preliminary examination of the Harvard objective-prism plates of β Lyræ, which Professor E. C. Pickering has kindly turned over to me for investigation, one of the striking points noticed is the predominance of helium lines in the spectrum.

Although the wave-lengths have not yet been definitely determined, it seems certain that all of the lines assigned by Runge and Paschen to the so-called "heavier constituent" of helium, within the limits of good definition on the plates, are present in the form of complex bands with bright and dark components. These are, by series, (*a*) λ 3889; (*b*) λ 4472, 4026, 3820; (*c*) λ 4713, 4121, 3868. The most conspicuous groups of bands in the photographic spectrum of β Lyræ are those at $H\zeta$ (λ 3889) and at λ 4472. The remarkable complexity of the first group is now at once explained by the fact that the complex helium group is added to (possibly at times overlapping) the complex hydrogen group ζ. The bands at λ 4026 and λ 3820 are striking, although apparently less complex than those at λ 4472. The lines of the third series (*c*) are not especially prominent, and it is possible that the last one, at λ 3868, does not show bright components.

One peculiar feature of β Lyræ lies in the fact that the bright component lines, both of hydrogen and helium, seem relatively much less intense in the ultra-violet, so that the bright components are very faint, and often invisible in $H\eta$ and $H\theta$, and always invisible (on these plates) in the upper hydrogen lines, although the dark components may be strong.

The so-called "lighter constitutent" of helium is also abundantly represented in β Lyræ. λ 5016 is found on a few plates which extend unusually toward the red, and λ 3965 is probably one of the outlying bands of the complex H group. The lines at λ 4922, 4388 (quite conspicuous), 4144, 4009 seem certainly present; λ 3927 may be an outlying member of the K group, which varies considerably in appearance, and λ 3834 may possibly be combined with $H\eta$; λ 3872 has not been seen. In the third series, λ 4438 does not appear to be present, a fine dark line only having been observed at that point on but one of the

plates thus far examined. λ 4169 is probably present; whether λ 4024 is a part of the group near λ 4026 cannot yet be stated; λ 3936 might possibly complicate the K group, as λ 3838 might affect $H\eta$; λ 3878 seems to be absent.

The remarkable displacements to which most of the lines in the spectrum of β Lyræ are subject makes the determination of the normal wave-lengths of the lines very difficult, but enough is now known to show the predominance of helium in the photographic spectrum, with hydrogen a strong second. Aside from Mg and Ca, the comparatively few other lines present cannot be identified with known elements.

EDWIN B. FROST.

DARTMOUTH COLLEGE,
Nov. 11, 1895.

ON THE WAVE-LENGTH OF THE D_3 LINE IN THE SPECTRUM OF THE CHROMOSPHERE.

IN the November number of the *American Journal of Science* Mr. A. DeForest Palmer has presented the results of a determination of the wave-length of the D_3 line in the spectrum of the chromosphere, made at the Johns Hopkins University in 1893. The spectrometer employed was that previously used by Bell in his investigation on the absolute wave-length of the D lines. The plane grating, having about fourteen thousand lines to the inch on five inches of ruled surface, is mounted at the intersection of the axes of two fixed telescopes, each of $16^{cm}.4$ clear aperture and $2^{m}.5$ focal length. The first order spectrum was used in all the observations, on account of its superior definition. Sunlight was reflected from a Foucault heliostat upon an achromatic lens of about four inches aperture, which formed an image of the Sun about one centimeter in diameter upon the slit. By means of a total reflection prism any part of the limb could be made tangent to the slit. Under these circumstances the D_3 line appeared as a short but very bright line in the center of the field of view. Its definition and intensity were found to vary with the position angle and also with the time of the observation. The best measures were made on very clear days at points in the chromosphere away from prominences. Seven lines selected from Rowland's "Table of Standard Wave-lengths" were used as standards in seventeen series of measurements, each consisting of equal numbers of settings on opposite ends of a solar diameter; the effect of rotation was thus eliminated.

The final value obtained for the wave-length of the D_3 line is given below, together with the wave-lengths of the same line as determined by Rowland and Hale, and those of the bright and faint components of the double line photographed by Runge and Paschen in the spectrum of clèveite gas:

Line	Source	Wave-length	Observer
D_3	Chromosphere	5875.982	Rowland
"	"	5875.939	Palmer
"	"	5875.924	Hale
Double: bright component	Clèveite gas	5875.883	Runge and Paschen
Double: faint component	"	5876.206	Runge and Paschen

There can now be very little doubt that the large values obtained in every case for the wave-length of D_3 in the spectrum of the chromosphere do not exactly represent the center of the bright component, but rather some point between the two lines, as I suggested in a note in the August number of this JOURNAL. The duplicity of the line is not mentioned by Rowland, and Mr. Palmer's note has nothing to say on this point. Both of these observers, however, used a very small image of the Sun, and it is not surprising that the faint component was not seen. With good atmospheric conditions it is an easy object in fairly bright prominences, but in the chromosphere it is seen with difficulty, on account of the increased broadening near the Sun's limb. Under these circumstances settings cannot be made on the center of the bright component, and the presence of the faint component on the lower side of the line tends to increase the measured value of the wave-length. That the results obtained by different observers agree so poorly among themselves can probably be explained by variations in vision, in atmospheric conditions, and in the instruments employed.

As remarked in my previous note, my own results were necessarily based on but few measures, and are to be regarded as preliminary. On account of the bad atmospheric conditions prevailing here during the greater part of the year I can hardly hope to obtain new measures before next summer.

GEORGE E. HALE.

Reviews.

UNTERSUCHUNGEN ÜBER DIE SPECTRA DER HELLEREN STERNE.

Part II (pp. 171–335) of the seventh volume of the Potsdam Publications, containing Scheiner's researches upon the photographic spectra of about fifty of the brightest stars, has been awaited with much interest since the publication, three years ago, of the first part of the volume, devoted to Vogel's spectrographic investigations of the velocities of stars in the sight-line. For that purpose it was necessary to secure spectra as sharp as possible in a very limited region near $H\gamma$, but nevertheless the plates obtained gave adequate definition over a range from about F nearly to H (a length of about 70^{mm}) for precise quantitative and qualitative examination, hence Part II is in the nature of a valuable by-product in the researches on sight-line velocities. The plates were taken in the period from the autumn of 1888 to the spring of 1891.

The spectrographic method, as devised by Vogel, was described at length in Part I and elsewhere, and indeed the results of the investigations now under review have been to a considerable extent anticipated in Scheiner's *Astronomical Spectroscopy*. The first forty pages of Part II are occupied with a discussion of the methods adopted for determining the wave-lengths of the lines, which were necessarily different for spectra with numerous lines than for those with few lines, and with a list of solar metallic lines used for comparison and identification. Ninety pages are given to the detailed measures of the wave-lengths of the stellar lines, and the last twenty pages are devoted to special studies of individual lines and deviations from normal types.

A clear statement is given at the outset of the difficulties encountered in making the microscope measures upon what (with the necessarily limited dispersion of the spectrograph) appear as diffuse bands but are really groups of lines, as, for instance, may be seen from a photograph, with powerful dispersion, of the corresponding portion of the solar spectrum. Unless the strongest lines are at the middle of such a group the maximum of intensity on the negative will not fall at

the middle of the band, hence a setting on the middle of the band would differ from one on the point of maximum intensity, with a corresponding uncertainty as to exactly what has been measured.

Professor Scheiner has based his wave-lengths upon the so-called Potsdam system,—which will be regretted by most spectroscopists, among whom Rowland's standards have now so generally been adopted. While admitting the superiority of Rowland's atlas, and the greater relative accuracy of the (then comparatively few) standard wave-lengths published by Rowland, his need of a complete list of *all* the solar lines is assigned as the chief reason for using the Potsdam wave-lengths. It should be remarked that at the time the work was done, Rowland's comprehensive "table of solar spectrum wave-lengths," now in progress of publication in this JOURNAL, was of course not available. But Scheiner adds: "Another important consideration was influential in making the choice of the Potsdam system. The basis of the Potsdam absolute wave-lengths has been published in complete detail in the fifth volume of the Potsdam publications, so that every one is in position to form his own judgment as to the reliability of the measurements and reductions, and such a control is very necessary when the introduction of a system is concerned. This is not possible of the Rowland system, in fact one can hardly speak definitely of a Rowland system, since the wave-length of D_1, upon which it is based, has been repeatedly altered of late and apparently is still continually subject to changes." [However, for ordinary work on stellar spectra, the difference between the two systems is comparatively slight, the corrections to reduce from Potsdam to Rowland being: at $\lambda 4000$, -0.079 tenth-meters; at $\lambda 4400$, -0.087; at $\lambda 4800$, -0.094 tenth-meters.]

For measuring spectra with numerous lines, a negative of the solar spectrum, taken under average conditions of adjustment, served as the standard, one hundred lines between $\lambda 4000$ and 4860 being selected as "normal lines." These lines were carefully measured on this plate and thus the distance in millimeters of each line from the $H\gamma$ line was obtained and platted as ordinate to the known wave-length as abscissa. In order that hundredths of a tenth-meter could be accurately read off, the scale had to be large, the length of the curve reaching seven meters. From the curve an interpolating table for transforming mm. distances into $\mu\mu$ was calculated for the intervals between each pair of normal lines. On the star plates the normal

lines were identified by placing the Sun plate, cut in halves lengthwise, film down on the star plate, so that the normal lines in the latter were the continuations, or nearly so, of the marked normal lines on the Sun plate. Of course the resulting wave-lengths are obtained on the assumption that the wave-lengths of the normal lines in the star are precisely the same as in the Sun, or in other words, the identification of the normal line in the star is assumed. The wave-lengths are given to hundredths of a tenth-meter.

An equal accuracy could not be attained in spectra with few lines, since for stars of Class Ia, there is practically only $H\gamma$ to serve as a point of reference; whence it was necessary that the difference in dispersion as compared with the solar plate be determined from every plate from the data as to temperature during the exposure, and setting of the camera objective. This difference in dispersion was obtained empirically by comparing the measured distance between the artificial F and $H\gamma$ lines (on the comparatively few star plates showing both distinctly) with the same distance of the dark lines in the solar negative. The approximate correctness of this procedure was checked by two other empirical methods, but the final accuracy suffers from the necessary uncertainty of these corrections, which now give the quantities required to reduce the distances from $H\gamma$ on the star plate to those on the solar plate. The two plates were next brought together under the microscope as in the first method, and settings were made upon each star line and the nearest normal line on the solar plate, which gave the distance of the unknown star line from the artificial $H\gamma$ line, and that of the normal solar line from the solar $H\gamma$ line, and from these the final wave-length was deduced.

In order to identify the lines in stellar spectra with the elements producing them, Scheiner was obliged to make out a list, based upon the metallic spectra of Kayser and Runge, Thalén, and Rowland, of all the lines in the Potsdam catalog of the solar spectrum, between $\lambda 4001$ and 4863, with which metallic lines coincide. Not quite a thousand lines, whose identification was fairly certain, were obtained for future reference in the progress of the work.

In spectra of Type I a special examination was made of the distribution of light in the broad $H\gamma$ line. Scheiner advocates the view that the breadth and haziness of the hydrogen lines is due to the great extent of the atmospheres of these stars,—supposed to be of the same order as the diameter of the photosphere. Then the absorp-

tion spectrum of the photosphere and the emission spectrum of the atmosphere would be optically superposed, the bright lines upon the dark, and the effect of the former would be proportional to the relative height of the atmosphere (as that would determine the relative *quantity* of light received from the two sources). Scheiner distinguishes three species, with eight varieties, of light-curves giving the distribution of light in the resulting line. In the first three varieties the height of the atmosphere being supposed slight, the intensity falls off uniformly from the edge to the middle of the dark line, the steepness of the curve varying with the contrast in temperature between photosphere and atmosphere. Next the height of the atmosphere is supposed to be so considerable that the effect of the superposed bright line begins to be seen, the intensity falling off sharply at the edges but rising to a secondary maximum in the middle, or at least remaining uniform, or falling off hardly at all even at the edges,—three varieties. In the third species the supposed great height of the atmosphere gives the bright lines the predominance, the effect of the dark lines being observable only at the edges, or not at all,—two varieties. The first variety of this last species of line is considered to correspond with the $H\gamma$ line in γ Cassiopeiae. Examples of the first species of curves are found in α Lyræ, α Canis majoris, β and δ Leonis; of the second, in α Virginis, η Ursæ majoris, γ and δ Orionis. In the case of the last star the $H\gamma$ line is so narrow, but brightened up in the middle, that but little more brightening would make the line invisible. The author states that in this case "δ Orionis would be an example of a star without hydrogen lines," but it would be safer and more accurate to say "without the $H\gamma$ line," for in the light of recent observations made elsewhere we are not at liberty to judge with certainty as to the behavior of the other line from the appearance of one line even of the same series.

As to individual spectra, in the case of α Aquilae, Scheiner favors the view (suggested by Pickering for other stars) that here two component stars, one of the first class, the other of the second, produce a composite spectrum, similar to that of the Sun, but the lines peculiar to Type Ia relatively conspicuous. In the case of Procyon, Scheiner does not consider such an explanation possible, regarding the spectrum merely as in transition from Ia to IIa. The two plates of Cassiopeiae that were examined showed no lines except bright $H\gamma$, although quite conspicuous dark lines have been photographed by several other

observers,—another illustration that we must not infer too much as to the character of the whole spectrum from the study of a limited part of it.

We cannot here discuss the details of the spectra of the different types, which have been to a considerable extent already anticipated by other investigators, and in previous publications by Scheiner himself, and so we pass to the important section on special researches on individual lines. The magnesium line at λ 4481 has received especial attention. It is present in nearly all Ia spectra, and appears faintly in a few of Type IIa. It varies greatly in intensity in different stars (there is no suggestion of it in α Ophiuchi, of Class Ia), and from its behavior antithetic to that of another Mg line, at λ 4352, in stars and in the laboratory, Scheiner finds a criterion of stellar temperature. He concludes that the temperature of the so-called absorbing layer — the uppermost stratum of the photosphere — is in stars of Class IIIa approximately that of the electric arc (3000°–4000° C.); in the Sun and stars of Class IIa, it is higher, but does not reach the temperature of the spark of a Leyden jar; in stars of Class Ia, it is approximately that of this spark (upper limit about 15000° C.).

A particularly interesting line, characteristic of all Orion stars of Class I, and later found by Scheiner in β Persei, α Virginis, β Tauri and η Ursæ majoris, is that at λ 4471, heretofore called the "Orion line." Since the memoir was published it has been proven to be due to helium, and (as suggested here by Scheiner) coincides with the well-known chromospheric line "*f*," as well as with a strong line in the nebular spectrum. From the similarity in its behavior to the $H\gamma$ line, Scheiner had concluded that the element producing it must be closely related to hydrogen, but possibly with a lower atomic weight. An idea of the accuracy of the measures of its wave-length may be gained by comparison with the determinations on laboratory helium. Scheiner gives $\lambda = 4471.75$, which on Rowland's scale would be 4471.66. Runge and Paschen find for the two components λ 4471.85 and 4471.66.

Another line attracted attention from its appearance in three of the Orion stars (β, ϵ, and γ) and α Virginis. Its wave-length was found to be 4388.30 (or 4388.21 on Rowland's scale). It has since been found with helium in the spectra of mineral gases, falling according to Runge and Paschen at λ 4388.11 in the second harmonic series of their so-called "lighter constituent" of helium.[1]

[1] Might the reviewer suggest the use for the present of the symbol *He* for the so-called "heavier constituent" or "helium proper," and *he* for the "lighter constituent"?

Other lines at λ 4384.16, 4233.59, 4468.64, and 4549 (group) are especially discussed, but their identification remains uncertain.

The memoir next gives the average spectrum of Type IIa, from the mean of the wave-lengths of the lines in α Bootis, α Aurigae, β Geminorum, α Tauri, and α Arietis, with a comparison with the Sun; and then follows a list of the lines in Type IIa-IIIa which deviate in their appearance, or are absent from the solar spectrum. Scheiner concludes that "the cause is the same for the (in instances) very considerable variation in intensity of the lines in the different stars." From a special comparison of the marked variation of α Persei (IIa), and its similarity to α Cygni (Ib), the opinion is reached that α Persei formerly had a spectrum similar to that of α Cygni, so that a missing link,—a transition stage from Ib to IIa,—is discovered.

The "*Schlussbetrachtungen*" of the author occupy the last three pages of the memoir, and it is difficult to condense them into less space. These new observations are not confirmatory of Schmidt's solar theory, being more readily explained by the old theories than by it. Kirchoff's Law should not be rejected but enlarged, its old form to be retained until we know what, if anything (luminescence ?), is to be substituted in it for temperature. Views on the evolution of heavenly bodies: the fundamental difference between the stellar and the nebular spectrum is the strong continuous spectrum, which might be produced either by gases under high pressure or by incandescent products of condensation (like our clouds of aqueous vapor). Adopting the latter origin, the attempt is made to show that with the cooling of a star the hydrogen lines gradually diminish in breadth while the metallic lines become stronger. A star of class Ia is a gas ball with an extensive atmosphere of hydrogen, all the other metallic gases are so far inside the photosphere (at a temperature comparable with the electric arc) as to produce no appreciable absorption. The radiation into space brings contraction, which keeps up the temperature inside, but the temperature contrast of atmosphere and photosphere becomes sharper, so that metallic lines begin to appear. Thus finally class IIa is reached. It is not important that the temperature of the photosphere in class IIa should be much less than in Ia, but that, in consequence of the contraction, the rate of fall of temperature outside of the photosphere is very much greater. The time cannot be determined when contraction ceases to compensate for radiation, since we do not know whether the decreased intensity of the more refrangible spectrum in Type IIa, and still more

in IIIa, is due to a diminution in radiation or an increase in absorption. When the temperature of the photosphere is so reduced as to be comparable with that of the electric arc, it is plausible that stable chemical compounds should form, giving the characteristic spectrum of Type III. Ic must precede Ia in order of evolution, but the data here used cannot apply back of Ic, or beyond IIIa.

The permanent objection to the above theorizing is that the ascending branch of the temperature curve for stars (those growing hotter) is still unprovided for; but theorizing occupies only a minimum space of this volume.

It cannot be forgotten that only a very few stars could be discussed, and these only for a limited part of their spectrum. Classes IIIb and IIb do not occur in the list of stars, and hardly Ic.

An equally careful study, with orthochromatic plates, should be undertaken for the lower part of the spectrum of the same stars, and the number of stars should be increased as far as the optical power of the telescopes permit. The number of spectrographs now attached to large refractors in this country ought to allow such a work to be begun here. Large reflectors, too, could be especially serviceable.

F.

Molecules and the Molecular Theory of Matter. A. D. RISTEEN, S. B. (Ginn & Co., Boston, 1895.)

IF one were required to characterize in a single phrase the physics of the nineteenth century, as distinguished from that of the two immediately preceding centuries, he might perhaps say that modern physics is a molecular science: the older physics a molar science. For nearly all problems in physical science, including the whole of chemistry, elasticity, capillarity, light, heat, electricity, and magnetism, involve explicit reference to molecular changes.

Any attempt, therefore, to discuss "molecular theories" within the limits of one volume must at least be called bold: unless the discussion degenerates into a mere enumeration of facts, or is confined to some limited portion of the subject.

Nevertheless, the volume before us is an excellent presentation of modern views concerning the "Molecular Theory of Matter," which means nothing less than the whole field covered by Physics, Chemistry and Physical Chemistry.

The first third of the book is devoted to the kinetic theory of gases: both methods and results are presented in a clear and scholarly manner. This is the best chapter of the work, because the author, while not exceeding the limits of a *résumé*, goes into some detail, and makes the treatment much less "scrapy" than other portions, *e. g.*, the one page devoted to *Electrolysis*, or the three pages given to the *Electromagnetic Theory of Light.* All that is said concerning gases will repay careful reading, for some of the more recondite points are made very clear.

In the subsequent portions the author covers a tremendous amount of ground, theories of capillarity, solution, osmotic pressure, dissociation, etc.; theories of light, gravitation, etc., with the result that only in very few places has he risen above the level of the ordinary text-book. However, in a treatment avowedly popular one can hardly say that these limits should be exceeded. The chapter on "*Molecular Magnitudes*" is clear and valuable.

One of the chief merits of the volume as a whole is that the author has throughout drawn a fairly sharp line between experimental facts and speculations. No one talks about molecules with such reckless freedom as the beginner: and, for many a beginner, such a book, even with the warnings it contains, would be positively dangerous, as tending to lessen his respect for such experimental data as Burns describes,

> "But Facts are cheels that winna ding
> An' downa be disputed."

Several pages are devoted to *High Vacua*, but one looks in vain for any mention of Lenard's work on *Cathode Rays*, which must be considered as rendering quite untenable the views of Crookes here described.

One other remark concerning the book as a whole: excellent as it is, its value would have been greatly enhanced by some critical estimate of the comparative value of the many methods there described; they are left too much on a par, and the reader is not satisfied. But such comparison is a difficult art, one acquired, perhaps, only after the man has actually been over the ground in an experimental way.

The book is an important contribution to the literature both of Chemistry and Physics.

H. C.

On the Electrolysis of Gases. J. J. THOMSON. *Proc. R. Soc.* **58**, No. 350.

AT various intervals during the last five or six years Professor J. J. Thomson has published the results of a series of beautiful and remarkable experiments, made with a view of determining the manner in which electricity is conducted by gases. The series has now culminated in a paper which may be considered as a definite proof that the process is one of electrolysis.

The results of the work previously done are, for the most part, contained in his "Recent Researches in Electricity and Magnetism." It is there shown that the velocity of the electric discharge in vacuum tubes is about one-half that of light, but varies greatly with the dimensions of the tube and the pressure of the gas; that the energy necessary to project charged molecules of gas at that velocity is much greater than the electric energy furnished to the tube, and that therefore, the process cannot be one of pure convection, though in certain portions of the tube it is probably of this character. It is also shown that when a discharge is passed through steam, under certain conditions, oxygen and hydrogen are liberated at the anode and kathode in the same quantities as at the terminals of a voltameter placed in the circuit.

In Professor Thomson's latest experiments two forms of vacuum tubes were used; one with a very fine capillary bore, the other fairly wide and with a metallic partition in the middle placed perpendicularly to the line joining the electrodes. In both tubes the electrodes are at the ends, consequently in the wider tube the discharge, after leaving the anode, passes through the metallic partition and thence to the kathode, making the side of the metallic partition at which it entered a kathode, and that by which it left an anode. The advantage of this latter form of tube is that the spectra of both anode and kathode can be observed simultaneously.

The experiments were made by introducing a small quantity of pure and dry gas into a tube, passing a discharge through it, and observing through the spectroscope the nature of the gas at the electrodes. The general results were as follows: When the discharge is passed through a compound gas, such as HCl, HBr, BrCl, the discharge is at first uniform in color, but after the lapse of a few minutes the parts surrounding the electrodes become colored differently and the spectroscope shows that the negatively charged ion has gone to the anode

and the positively charged one to the kathode. If the current be reversed, the spectra flash out more brightly at first, but remain in their old positions for a time, then disappear, and finally make their appearance again at the electrode opposite to that at which they were originally. The nature of the charge on a gas atom may vary. When HCl and HBr are electrolysed in the tube, Cl and Br both go to the anode. But when BrCl is placed in the tube, the Br goes to the kathode, showing that the sign of its charge has changed. When an electropositive element is substituted for an electronegative one, as in $CHCl_3$, the hydrogen goes to the anode, showing that it has a charge of the same kind as that of the Cl atom which it has replaced.

The most important results, however, from the point of view of the spectroscopist, are those in which simple substances were subjected to the discharge. From these it appears that carbon, hydrogen and nitrogen have different spectra according to whether they are charged positively or negatively. Positively charged carbon shows the CO spectrum, negatively charged carbon shows the candle spectrum. Positively charged hydrogen shows the green line brighter than the red, with negatively charged the reverse is the case.

It is conceivable that these differences might be due to a higher temperature at one electrode than at the other. But Professor Thomson meets this objection by pointing out that when the current is reversed, so far from the spectra reversing at once, they become intensified, keeping their old positions, then disappear and finally appear again at the opposite electrodes, a result which would seem to negative any such supposition. He adduces further evidence, from the observed behavior of carbon compounds which do disassociate when the current has been passed through for a time, tending to confirm his theory.

Reginald A. Fessenden.

RECENT PUBLICATIONS.

AT the second annual meeting of the Board of Editors of THE ASTROPHYSICAL JOURNAL, recently held at the Harvard College Observatory, it was voted that an attempt be made to increase the scope of the bibliography of astrophysics and spectroscopy published under the heading "Recent Publications." In their present form the monthly lists of recent papers no doubt serve a useful purpose, though they make no claim to completeness. It is evident, however, that a bibliography which derives its titles mainly from the more accessible journals, the annals of the more important societies and the publications of observatories may be of no great value: it should also include publications of obscure origin. Papers of great importance frequently appear in the annals of the smaller societies, or are published at irregular intervals by institutions or individuals. In many cases but few copies of such papers are distributed, and consequently it sometimes happens that contributions of great value are overlooked for years.

It is now proposed that all who are interested in the formation of a complete bibliography of astrophysics and spectroscopy give their assistance by forwarding such titles as come to their notice. The bibliography is intended to cover all investigations of radiant energy, whether conducted in the observatory or in the laboratory. Special mention may be made of photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

To those who express themselves as willing to assist in this work cards conveniently arranged for the insertion of titles will be sent. These can be filled out, and mailed to the JOURNAL from time to time. Authors of papers are requested to send copies to Professors Hale and Keeler, in order that the titles may certainly find a place in the bibliography, and also for the purpose of review. If for any reason copies cannot be sent the title alone will serve for insertion in the bibliography.

The following list includes the serial publications from which the

greater part of the titles now appearing in the bibliography are obtained. The abbreviated title is given in a parenthesis following the full title. Where none appears it is understood that the full title is to be used.

The editors will continue to index these publications, and the request for titles therefore applies only to papers not contained in them. This restriction does not include reprints of papers. These will be welcome, from whatever source they may be derived.

Papers, titles, or offers of assistance should be addressed to George E. Hale, Kenwood Observatory, Chicago, or to James E. Keeler, Allegheny Observatory, Allegheny, Pa.

Abhandlungen der K. Akademie der Wissenschaften zu Berlin (Abh. d. K. Akad. d. W. Berlin).
Abhandlungen der K. Bayrischen Akademie der Wissenschaften zu München (Abh. d. K. Akad. d. W. München).
American Chemical Journal (Am. Chem. Jour.).
American Journal of Science (Am. Jour. Sci.).
American Meteorological Journal (Am. Met. Jour.).
Annalen der Physik (Wied. Ann.).
Annales de chimie et de physique (Ann. Chim. et Phys.).
Annales ne l'école normale supérieure (Ann. école norm. supérieure).
Annuaire du Bureau des Longitudes.
Anthony's Photographic Bulletin (Anthony's Photo. Bull.).
Archives des sciences physiques et naturelles (Arch. de Genève).
Archives Néerlandaises des Sciences (Arch. Néerlandaises).
Astronomical Journal (Ast. Jour.).
Astronomische Nachrichten (A. N.).
Astrophysical Journal (Ap. J.).
Atti della R. Accademia di Roma (Atti d. R. Accad. di Roma).
Berichte der Deutschen Chemischen Gesellschaft (Chem. Ber.).
Berichte über die Verhandlungen der K. Sächsischen Gesellschaft der Wissenschaften in Leipzig (Ber. d. K. Gesell. d. W. Leipzig).
British Journal of Photography (Brit. Jour. Photo.).
Bulletin astronomique (Bull. Astr.).
Bulletin de l'académie impériale de St. Pétersbourg (Bull. Acad. St. Pétersbourg).
Bulletin de l'académie royale de Belgique (Bull. Acad. R. Belgique).
Bulletin de la société astronomique de France (Bull. Soc. Astr. France).
Bulletin de la société chimique de Paris (Bull. Soc. Chim. Paris).
Bulletin de la société impériale des naturalistes de Moscou (Bull. Soc. Nat. Moscou).
Chemical News (Chem. News).
Ciel et Terre.

Comptes rendus de l'Academie des Sciences (C. R.).
Electrician.
Elektrotechnische Zeitschrift (Elektrotechn. Zeitschr.).
English Mechanic (Eng. Mech.).
Engineering.
Himmel und Erde (Him. u. Erde).
Jahresbericht der Chemie (Jahresber. d. Chem.).
Johns Hopkins University Circulars (J. H. U. Circulars).
Journal de physique théorique et appliquée (Jour. de Phys.).
Journal für praktische Chemie (Jour. prakt. Chem.).
Journal of the British Astronomical Association (Jour. B. A. A.).
Journal of the Chemical Society of London (Jour. Chem. Soc. London).
Journal of the Franklin Institute (Jour. Franklin Inst.).
Knowledge (Knowl.).
Mathematische und Naturwissenschaftliche Berichte aus Ungarn (Ber. aus Ungarn).
Memoirs of the British Astronomical Association (Mem. B. A. A.).
Memoirs of the Royal Astronomical Society (Mem. R. A. S.).
Memorie della Società degli Spettroscopisti Italiani (Mem. Spettr. Ital.).
Meteorologisches Zeitschrift (Meteorolog. Zeitschr.).
Monthly Notices of the Royal Astronomical Society (M. N.).
Nachrichten von der K. Gesellschaft der Wissenschaften und der Georg-August Universität in Göttingen (Gotting. Nachr.).
Nature (Nat.).
Naturwissenschaftliche Rundschau (Naturw. Rund.).
Nuovo Cimento.
Obers. K. Danske Vidensk. Selskabs. Forhandl. Kobenhavn.
Observatory (Obs'y.).
Philosophical Magazine (Phil. Mag.).
Philosophical Transactions of the Royal Society of London (Phil. Trans.).
Photo-Beacon.
Photographic News (Photo. News).
Photographic Times (Photo. Times).
Physical Review (Phys. Rev.).
Popular Astronomy (Pop. Astron.).
Proceedings of the American Academy of Arts and Sciences (Proc. American Acad.).
Proceedings of the Cambridge Philosophical Society (Proc. Cambridge Phil. Soc.).
Proceedings of the Physical Society of London (Proc. Phys. Soc. London).
Proceedings of the Royal Institution (Proc. R. Institution).
Proceedings of the Royal Society of Dublin (Proc. R. Soc. Dublin).

Proceedings of the Royal Society of Edinburgh (Proc. R. Soc. Edinburgh).
Proceedings of the Royal Society of London (Proc. R. Soc.).
Publications of the Astronomical Society of the Pacific (Pub. A. S. P.).
Rendiconti dell' accademia delle science fisiche et matematiche di Napoli (Rend. R. Accad. di Napoli).
Rendiconti della R. Accademia di Roma (Rend. R. Accad. di Roma).
Report of the American Association for the Advancement of Science (Report A. A. A. S.).
Report of the British Association for the Advancement of Science (Report B. A. A. S.).
Science.
Séances de la société française de physique (Séances Soc. Franc. Phys.).
Sirius.
Sitzungsberichte der K. Akademie der Wissenschaften zu Berlin (Sitz. d. K. Akad. d. W. Berlin).
Sitzungsberichte der K. Bayrischen Akademie der Wissenschaften zu München (Sitz. d. K. Akad. d. W. München).
Sitzungsberichte der mathematische-naturwissenschaftliche Classe der K. Akademie der Wissenschaften, Wien (Sitz. d. K. Akad. d. W. Wien).
Sitzungsberichte der Physikalisch-Medicinischen Societät in Erlangen Sitz. d. Phys. med. Soc. Erlangen).
Svenska vetenskaps Akademiens Handlingar (Svenska vetensk. Akad. Handl.).
Technology Quarterly (Tech. Quarterly).
Transactions of the Astronomical and Physical Society of Toronto (Trans. Ast. Phys. Soc. Toronto).
Transactions of the Royal Society of Dublin (Trans. R. Soc. Dublin).
Transactions of the Royal Society of Edinburgh (Trans. R. Soc. Edinburgh).
Verhandelingen der Koninklijke Akademie van Wetenschappen te Amsterdam (Verhand. K. Akad. Wetens. Amsterdam).
Verhandlungen der Schweizeschen Naturforschenden Gesellschaft (Verh. d. Schweiz. Naturforsch. Gesell.).
Verslagen van de Zittingen der Wis-en Natuurkundige Afdeeling van de Koninklijke Akademie van Wetenschappen te Amsterdam (Verslagen K. Akad. Wetens, Amsterdam).
Vierteljahrschrift der Astronomischen Gesellschaft (V. J. S. Astr. Gesell.).
Vierteljahrschrift der Naturforschenden Gesellschaft in Zurich (V. J. S. d. Naturforsch. Gesell. in Zurich).
Wilson's Photographic Magazine.
Zeitschrift für der physikalischen und chemischen Unterricht (Z. f. d. Phys. u. Chem. Unterricht).

Zeitschrift für Elektrotechnik und Elektrochemie (Z. f. Elektrotech. u. Elektrochem.).
Zeitschrift für Instrumentenkunde (Z. f. Instrum.).
Zeitschrift für Mathematik und Physik (Z. f. Math. u. Phys.).
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NOTICE.

The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

The Editors do not hold themselves responsible for opinions expressed by contributors.

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